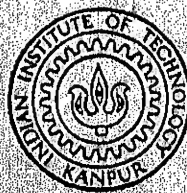# CINDER AS A FILTER-MEDIA IN DUAL-BED WATER FILTERS

By

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DEPARTMENT OF CIVIL ENGINEERING
INDIAN INSTITUTE OF TECHOLOGY
KANPUR
AUGUST, 1971

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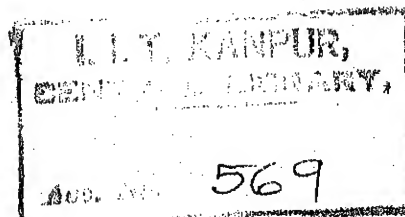## A THESIS

Submitted in Partial Fulfilment of the Requirements

OF

THE DEGREE

OF

MASTER OF TECHNOLOGY

By

SANTOSH KUMAR TIWARI

TO THE

DEPARTMENT OF CIVIL ENGINEERING
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AUGUST, 1971

CERTIFICATE
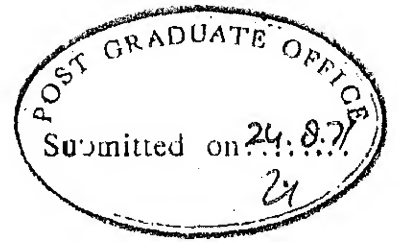
This is to certify that the present work

has been carried out by **Shri Santosh Kumar Tiwari**

under my supervision and the work has not been

submitted elsewhere for a degree.

Dr. Guru Dass Agrawal
Associate Professor
Department of Civil Engineering
Indian Institute of Technology,
Kanpur.

(i)

ACKNOWLEDGEMENT

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ABSTRACT

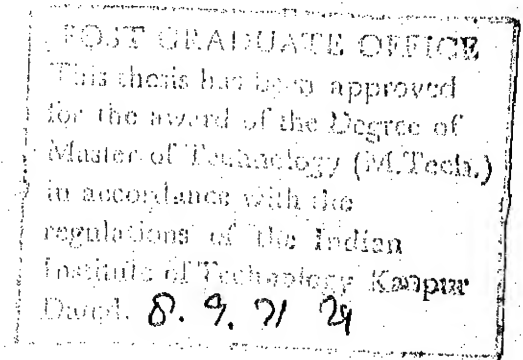All existing rapid sand filter plants in Indian cities contain single media bed that is sand. The increasing demand of treated water has created an urgent need to build new plants or to increase somehow the capacity of the existing plants. Use of dual media beds with anthracite layer over sand, has been accepted as one alternative to improve efficiency and increase capacity. Present work is part of the search for a material which can suitably replace the anthracite which is not available in India. Cinder, a waste product from all large size coal furnaces, e.g., railway locomotives, was found to be one material which is cheap and readily available locally and its suitability as a filter media was studied in the present work. A layer of 15 cm of cinder was used over the sand in the laboratory filter.

For an influent turbidity of 100 mg/l and flow rate of 2 gpm/ft^2 the length of run at 150 cm headloss in the filter bed increased from 31 hours for a single media sand filter to 43 hours for a dual media cinder sand filter. The cinder was found to posses the requisit properties of a filter media.

CHAPTER I

INTRODUCTION

1.1 SAFE WATER AS AN ESSENTIAL NEED

Water should be better than a certain minimum
quality so as to make it potable and safe for human consump-
tion. The most important quality of water is that it
should be free from disease causing organisms and should
not contain harmful chemicals. Ground water generally are
of better quality than surface waters but when we consider
the large quantities need, the problem in growing cities
becomes acute and we are left with no alternative but to
utilize surface waters after treatment. Even if successful
Family Planning campaigns are able to restrict the population
growth in the country as a whole, industrialization and
consequent migration to cities will keep on aggravating ever
increasing water demands of the cities. Even now it is the
urgent need of many Indian cities to produce more potable
water which is safe to drink and usable for domestic purposes.

1.2 FILTRATION AS THE CRUCIAL AND LIMITING STEP IN WATER TREATMENT

The treatment of water includes processes such
as sedimentation, coagulation, filtration and disinfection.
Plain sedimentation removes only coarser particles which are
settleable. Sedimentation with coagulation may remove large

quantity of colloidal particles. However the production of
clear and sparkling water, capable of being cheaply disinf-
ected to ensure against disease requires the use of a filter.
Filtration will also be needed if it is desired to remove
color, tastes, orors, iron and mangnese. Thus filtration
is the most essential process in treatment of If most surface
water as it has been stated above that there is an increasing
demand of treated water in most developing cities, one is
left with two alternatives; either to install a new plant
or to make certain modification in the existing plant. Amount
of water treated per day very much depends upon the capacity
of the filter. Therefore any modification in the existing
plant should be aimed to increase the capacity of the filters
as it is the rate limiting process in the scheme of water
treatment.

1.3 ALTERNATIVES FOR INCREASING CAPACITY OF FILTERS

Several alternatives are possible to increase the
capacity of the filter. There are two ways by which the
filter capacity could be increased, one is to increase the
rate of flow or to increase the length of run. Many of the
time the two have influence on one-another.

1.3.1 INCREASED LOAD ON NORMAL FILTERS

One way to produce more treated water could be

the increased flow would certainly reduce the length of run considerably and as soon as filter get choked it would be difficult to maintain a higher flow. Poor quality effluent may also be produced at the end of the length of run if there is a sudden variation in the flow.

1.3.2 UPFLOW FILTRATION

Length of run can be increased, if water is made to flow from the bottom to the top in a graded filter. As the water first passes through coarser material, the floc is distributed throughout the bed unlike that in a down flow filter in which top layers are clogged leaving rest of the bed unutilized. Since floc is distributed throughout the bed, more turbidity is removed and hence more gallons of water is treated. Higher rates of flow can also be used without decrease in effluent quality. The main disadvantage of this process lies with the fact that there is a tendency for the bed to expand because of the pressure differences overcoming the weight of the media. A higher depth of bed should be used to avoid this, but it would certainly mean an extra cost.

1.3.3 MULTILAYER FILTRATION

Most practical filters contain sand of non-uniform size and consequently the sand stratifies during the back-washing process to form a hydraulically size graded medium

in the filter. There is an inherent disadvantage in such graded filters because they become rapidly clogged at the top surface where the medium is finest, with consequent inefficient use of the lower layers of the filter. Such a situation has been recognized as inefficient because longer filter runs can be achieved when removed particle matter is distributed throughout the depth of the bed. One method of achieving such a situation is to pass the flow of water from coarse grains to fine grains in the down flow direction. This is possible only if the coarser fraction is of lighter material. That is called multilayer filtration. A reverse gradations is provided because of the density differential of the media and after backwashing coarser but the lighter material comes at top. Dual media beds of anthracite and sand have accomplished atleast a partial inverse gradation by exposing the coarser anthracite to the influent flow first. This results in full utilization of the filter bed and thus longer filter runs are possible. Anthracite-sand bed have been used in U.S.A. and Europe. A search has been made to find a suitable material in India. It was reported by R.K. Pandit (18) that suitable variety of coal was not available. More recently CPHERI has made a search to locate sources of anthracite in the country (40) and their finding was that no anthracite source is available. They investigated the use of bituminus coals which could replace the anthracite

but it has a high organic content. This organic material could be biologically degraded and thus the effluent water may contain undesirable chemicals. Bituminus coals are relatively costly too.

1.4 OBJECTIVE OF THE PRESENT STUDY

This study is part of a search for a cheap and suitable material to replace anthracite in multilayer filtration. Cinder, a waste by-product from boilers was found to be one material which is cheap and readly available around cities. The cinder used in this experiments was obtained from waste stack of KESA steam power station. This material is currently used only as a cheap filter and construction material. The present study is made to invest- igate as to how far the filter performance can be improved if this cinder is used at a top layer above a conventional sand filter.

CHAPTER II

LITERATURE SURVEY

2.1 HISTORY OF FILTRATION

Filtration through porous formations as a natural process has been responsible for cleaning water for ages. The need for water filtration was realized as early as 2000 B.C. (3), in a collection of medical maxims from the Ayurveda, in the chapter on water, it is directed to "treat foul water by boiling and exposing to sun light and by dipping seven times into it a piece of hot copper, then to filter and cool it in an earthen vessel."

Filtration through sand beds to clarify the Thames river water for community use was instituted by the Chelea water company, under the direction of James Simpson, in 1829. Because of the success of this installation, by 1852 filtration of all river water supplied to London was made compulsory by parliament. Dr. John Snow, in 1854 of the Broad Street proved the interrelatioship of the disease to sewage and drinking water. By 1865 many European cities were using filters but only in 1872 Kirkwood built the first successful slow sand filter plant at Poughkeepsie, New York. In 1892, the effectiveness of slow sand filter in removing pathogenic organisms was demonstrated by Hamburg Altona (1).

The principles of rapid sand filtration were

developed by experiments undertaken at Louesville, Kentucky,
from 1895 to 1897 under the direction of George W. Fuller.
The first rapid sand filter plant was built in Somerville
N.J. in 1885 (6). A typical modern filter was built in 1901
at Little falls, N.J. In a period of about 30 years the use
of these types of filters became world wide.

2.2 FILTRATION EQUATION

The main purpose of filtration of turbid water
is to remove turbidity from it. As the suspended matter
is removed from the flow and deposited in the bed, the
characteristics of the bed changes due to clogging. It is
however very difficult to formulate filter behaviour accomm-
odating all the variables involved in the filtration
operation. So the help of some parameters, dependent on
characteristics of the fluid, suspension and filter media, is
necessary to obtain the expression of the floc deposit and
the associated head losses for any depth of filter at any
time of run.

Iwasaki (5) in 1937 followed by Stein first
formulated the filter phenomenon in mathematical terms.
Based on his experiments with Potter's clay suspension, he
expressed the rate of removal of concentration of suspension
from flow as proportional to concentration.

$$C = C_0 e^{-\lambda L} \qquad (1)$$

where

C_o = concentration of the suspended matter in the influent (volume/volume ratio)

C = concentration of suspended matter at any depth of filter

L = depth below filter surface, and

λ = filter coefficient.

Filter coefficient depends on the characteristics of suspension, rate of filtration, water viscousity and the internal geometry of porous filter.

Iwasaki (5) and later Ives (14) suggested that efficiency of the filter initially increases from the start of the run as the floc is deposited. They gave a linear relationship between filter coefficient and specific deposit of floc as follows.

$$\lambda = \lambda_o + c\,\sigma \qquad (2)$$

where C = a rate factor parameter

σ = specific floc deposite or volume of material deposited per unit filter volume.

As the deposition increases, pores become constricted tending to increase the interstitial velocity and reduce the interstitial surface area of deposition. These actions will reduce the rate of deposition and thus λ

reduces and equation (2) is modifed by Ives (14) as follows

$$\lambda = \lambda_o + C\sigma - \phi\, \sigma^2/(f_o - \sigma) \tag{3}$$

where

f_o = initial porosity of the clean bed

ϕ = rate factor parameter.

In order to determine the filter equation, the filter parameters λ_o, C and ϕ have to be experimentally determined. Ives (26) and his co-workers have related the constants λ_o, C and ϕ to three fundamental parameters of the filter

$$\lambda_o = \frac{K_1}{dm\ V_o\ \mu^2} \tag{4}$$

$$C = \frac{K_2}{dm\ V_o\ \mu^{1.2}} \tag{5}$$

$$\phi = \frac{K_3}{dm\ V_o\ \mu^2} \tag{6}$$

where K_1, K_2 and K_3 are constants.

V_o = superficial velocity of filtration

μ = viscosity of water

dm = mean diameter of grain

Here also K_1, K_2 and K_3 are to be experimentally determined.

2.3 VARIABLES EFFECTING FILTRATION

Performance of a filter very much depends upon various factors such as filter media, influent turbidity, coagulant addition, rate of filtration etc. A knowledge of these factors will enable us to make suitable modifications in order to achieve a desired effluent quality and head loss distribution.

2.3.1 FILTER MEDIA

Size of the media would decide the amount of turbidity it can arrest. Simple screening of particles will be more in a fine grained media, but at the same time fine grains also contain larger surface area. It has been experimentally determined that adsorption is the most significant mechanism of removal, hence more surface area would mean more removal. Smaller layers of fine material may remove large quantity of turbidity but might produce excessive head loss. As an alternative we can choose larger depths of coarser material although all natural sands do contain certain amount of fine material.

Another property of the media is sphericity. Filter media having all spherical particles have more porosity and thus more space to store turbidity particles. Sphericity of particles is advantage, however smooth surfaces are not very much desired. Density of particles

do play a role, lighter particle will have more expansion
during backwash. Particles with lower density definitely
have lower settling velocity. It filter bed contains parti-
cles with different density, a combined effect of size and
density will decide the gradiation after filter backwash.

2.3.2 INFLUENT WATER TURBIDITY

Size of the particle or of the floc present in
turbid water is very important for the turbidity to be
removed. The electrical property of the floc (28) and Floc
strength (41) still play a greater role in the removal of
turbidity. Floc strength has been defined as the resistance
to fragmentation by shear induced by hydraulic velocity
gradient. A strong floc is formed rapidly under a high
velocity gradient, while a weaker floc will not grow in
size or will disintegrate under some conditions. During
filtration excessive floc-strength will cause bulk of the
floc to remain within the uppwr layers of the filter and
tendency for the break through will be smaller, but at the
same time it would mean a greater headloss. Some intermediate
strength is desired, where the floc gradually penetrates
into the bed for the removal of solids without premature
break through.

2.3.3 COAGULANT ADDITION

The principal function of coagulation is the

Acc. 569.

destabilization, aggragation and binding together of colloids. Chemical coagulation involves the formation of chemical flocs that absorb, entrap or otherwise bring together suspended matter which is colloidal in nature. As a normal practice coagulation before filtration has a beneficial effect (26), but the clogging of top layers can not be avoided. Bhattacharya A.K. (39) did experiments with coagulent addition into the bed. He found that clogging of top layer can be avoided and at the same time this increased the length of run. The amount of chemical needed for optimum functioning of the filter is also considerably reduced.

2.3.4 RATE OF FILTRATION

Over the years, the empirical rate of 2 gallons per squarefoot per minute has been the "standard" for the design of rapid sand filters. Baylis (42) concluded that for water not high in turbidity and turbid water properly conditioned, a high rate of filtration will not impair the quality of the effluent. He used 5 gallons per min per square-foot and obtained a relatively clear effluent. However it is apparent, if hydraulic filter controls and pretreatment conditions are in satisfactory operation.

2.4 FLOC DEPOSIT AND HEADLOSS DEVELOPMENT

When there is no floc deposited in the bed there is still some headloss due to obstruction produced by sand

grains. As the deposition starts there is further headloss development.

2.4.1   HEADLOSS IN A CLEAN FILTER

G.M. Fair (4) derived an equation for the hydraulic gradient through a bed of clean sand starting with Poisellve's equation as follows

$$i = \frac{32\gamma}{g} \cdot \frac{1}{(Dt)^2} \cdot v \qquad (7)$$

where i = hydraulic gradient

γ = kinamatic viscousity of fluid

g = acceleration due to gravity

Dt = tube diameter

Replacing Dt by average hydraulic radius and assuming that the material has a uniform grain size for a depth $\Delta\ell$, the headloss Δh can be given by following equation

$$\Delta h = 1.067 \frac{C_D}{g} \cdot \frac{1}{f^4} \cdot \frac{v^2}{d} \qquad (8)$$

$$d = \frac{\alpha}{\beta} \cdot \frac{V}{A} \qquad (9)$$

$$C_D = \frac{24}{R} + \frac{3}{\sqrt{R}} + 0.34 \qquad (10)$$

$$R = \frac{vd}{\gamma} \qquad (11)$$

where

Δh = loss of head in a depth Δl

v = velocity of water moving down upon the sand bed

g = acceleration due to gravity

f = porosity ratio of the filter bed

d = characteristic diameter of the grain

V = volume of the sand particles

A = area of the sand particles

R = Reynolds number

ν = kinamatic viscousity of water

α/β = 6.0 for spherical particles

     = 9.0 for angular particles.

This equation can also be applied to stratified bed considering each small layer to be uniform.

2.4.2 HEADLOSS IN A PARTIALLY CHOKED FILTER

Deb (23, p. 386) found out that the difference between the headloss at any time and the initial headloss is approximately proportional to specific deposit and may be expressed by following equation

$$\Delta h = \Delta h_0 + K \sigma \cdot \Delta l \tag{12}$$

where K is a dimensionless headloss coefficient, which is dependent on the characteristics of suspension and filter media.

In any small layer of filter media between depths L_1 and L_2, headloss across the layer may be written from equation 12

$$H_1 = \int_{L_1}^{L_2} h \, dl = H_{o1} + \int_{L_1}^{L_2} K \sigma \, dl \qquad (13)$$

where H_1 and H_{o1} are total and initial headlosses in that layer and if K is assumed to be constant for that layer

$$\int_{L_1}^{L_2} \sigma \, dl = \frac{H_1 - H_{o1}}{K} \qquad (14)$$

We now have the continuity equation as

$$\int_{L_1}^{L_2} \sigma \, dl = V \int_{o}^{t} \delta c \, . \, dt \qquad (15)$$

where

V = velocity of flow of water = $\dfrac{Q}{A}$

Q = flow of water through filter

A = area of the filter

C = concentration at any time t

from the equations (14) and (15) we can evaluate K as follows

$$K = \frac{H_1 - H_{o1}}{V \sum_{o}^{t} (C_1 - C_2) \, \delta t} \qquad (16)$$

where C_1 and C_2 are influent and effluent concentration for any uniform layer. This equation may also be applied in

stratified beds considering each small layer to be uniform.

2.4.3 LENGTH OF RUN AND CHOKING OF FILTER

Filter back washing is needed when headloss becomes very close to the head applied. Many a times filter back washing may be needed when effluent water is found to contain turbidity. As water containing turbidity is passed through the filter bed, the colloids start depositing. At a certain stage, the accumulated deposits can so construct the pore size that interstitial velocity will reach its critical value and no further deposition will take place in that layer. The value of λ then becomes zero and all particles are carried away to the next layer. At this stage specific deposit will reach its ultimate value of σ_u. This σ_u can be determined from equation (3) by differentiating and putting it to zero.

$$\lambda_o + C \sigma_u - \phi \sigma_u^2/(f_o - \sigma_u) = 0 \qquad (17)$$

or

$$\sigma_u = \frac{C f_o - \lambda_o \pm \sqrt{(\lambda_o - C f_o)^2 + 4\lambda_o f_o (C + \phi)}}{2(\phi + C)}$$

$$(18)$$

2.5 FILTER MODIFICATIONS AND THEIR EFFECT ON FILTER PERFORMANCE

In the recent years a number of studies have been made to improve the filter efficiency by changing the

distribution of floc through the bed, headloss patterns,
length of run and back wash characteristics. The changes in
these parameters which determine the filter efficiency have
been achieved by suitably modifying the filter variables
namely, filter media, rate of filtration, method of coagulant
addition and influent turbidity.

2.5.1 HIGHER LOADING ON CONVENTIONAL FILTERS

The average gravity flow rapid sand filter is
designed to function at the rate of 2 gal. per square foot
per min. But at many places filters have been over loaded
with no deterioration in the efficiency. Ives (14) reports
that 50 percent overloading has been successfully practiced
in U.S.A. Rates as high as 5 gal. per min. per square-foot
have been used for low turbidity waters (42). Although such
high rates certainly require the use of specific filter
conditions. In conventional filters the type and quantity
of influent turbidity can very much decide the allowed over
loading. If volume of water treated per unit of final
headloss is tapen as the index of efficiency of the filter.
A high value of this factor certainly means that the filter
has been used more efficiently. Another way to obtain more
treated water is to have greater length of run. In a conven-
tional filter the size of the top grain may be varied with
the depth of filter bed and with this, a significant

increase in the length of run has been noted (32, p. 82).
A composite data of 75 runs of various cities has been taken
which relates sand size, length of run and floc penetration
in a conventional filter (Table 2.1)

Table 2.1

Size of Top Sand (mm)	Depth of Top Sand (feet)	Filter Runs (hours)	Max. Floc Penetration (inches
0.37	0.20	28	3.0
0.43	0.22	38	4.5
0.50	0.25	48	6.0
0.60	0.30	66	9.0
0.76	0.33	97	11.0
0.95	0.40	118	16.0
1.17	0.50	137	24.0
1.75	0.66	156	47.0

2.5.2 UP FLOW FILTRATION

The idea of upward flow filtration had already
been investigated since 18th century (11) although with a
limited use because of the difficulties in back washing.
In Russia in 1953-54, several tests were made with up-flow
filters. They called the filter as contact clarifier1 (44).
A pilot plant study was made by R.K. Pandit of CPHERI (23).

He found out that long filter runs can be achieved with up

flow filtration as water first meets the coarser material

preventing the clogging of fine material at top. Other

advantages of upflow filtration over conventional filters

were that it required lower doses of alum when this was

introduced just at the inlet point. It was also found out

that rate of controlers were not needed and filtration was

carried on with a diminishing rate and satisfactory results

were obtained W.J. Diaper and K.J. Ives (30) also concluded

that longer filter runs were possible with upflow filtration.

The head loss in upflow filter was always lower because of

the more even distribution of solids removal.

2.5.3 BIFLOW FILTRATION

The main disadvantage of upflow filter is that

there is a danger of lifting top material at high rates. This

difficulty is overcome if water enters into the bed from

both the direction, part of it from the top and rest from the

bottom (21). The effluent is collected just below the fine

sand, although it will be determined by the influent turbidity.

As whole depth of bed is utilized more efficient performance

of filter can be expected higher flow rates (6 g.p.m.) have

been tried and satisfactory removal has been obtained. A

comparison between normal, upflow and biflow filters is

given in Table 2.2.

Table 2.2*

Comparison of Average Operating Characteristics of Contact Filters.

Operation	Units	Upflow filters	Biflow filters	Normal filters
(1)	(2)	(3)	(4)	(5)
Design filtration rates	gpm per sq. ft.	2	5	2.5
Maximum filtration rates	gpm per sq. ft.	2	6	3
Basic wash water rate	in per min.	20	21	16
Wash duration	min	8	6	5
Top layer wash water rate	in per min	0	8	0
Top layer wash water duration	min	0	1	0
Flushing rate through drainage pipes	in per min	0	13	0
Flush duration	min	0	2	0
Initial filtrate to waste duration	min	5	0	0
Time out of operation	min	28	24	20
Filter run	hr.	20	12	12
Operating cycle; run+wash	hr.	20.47	12.4	12.33
Mean annual coagulant dose (anhydrous salt)		20	25	25
Mean annual lime dose		0	6.6	6.6

*Reference No. 44.

2.5.4 MULTILAYER FILTRATION

A conventional filter which after back washing has finest material at top and coarser at bottom, has a disadvantage of being rapidly clogged. A reverse gradiation of filter bed is possible if more than one type of media is used. Larger sized media may remain at top if it has lower specific gravity than the sand. In 1931, crushed anthracite coal known as anthrafilt was used as filtering media over the sand. This anthracite had specific gravity of 1.65. Its particles are angular and flat with sharp edges and flat sides. Because of the angular particles the bed is less compact than a sand bed. Its increased size of voids permits a greater penetration of floc into the bed with resultant longer filter runs. Conley (17) have shown that filter made of anthracite and sand are superior to filters made of either material alone. The comparative study of many filters at Hanford (15) have shown that large capital savings was made possible by increasing the flow through all the components. Highest flow rate achieved was 8 g.p.m. per sq. ft. It was also concluded that higher rates can be achieved with more depth of anthracite but it required more chemicals. A number of laboratory and pilot plant studies have been made (17,24,25,30,36,37) and it has been well established that high filtration rates and longer filter runs have been obtained with anthracite-sand filter media. The same workers have also reported that

certain modification may be needed in the design of filter because of changed back wash characteristics. Since relative expansion of anthracite is more and in order to clean the bottom most layer of sand, total expansion needed will be more. To have more depth of sand, the gravel pack has been removed. This modification has been made at Hanford (15) and in place of gravel pack porous bottoms have been used.

Several conclusions were drawn about the use of these filter at various conditions, the investigations are still going. Riner (36) pointed out that grading of the dual media bed should be based on the type of water to be filtered and this type of bed would be more beneficial if high concentration of suspended material were to be removed.

Dual media beds, although have two different layers, but there is always a portion where both the media are inter-mixed. Camp (24) pointed out that the upper portion of sand layer, below the anthracite tends to clog easily and can be more difficult to clean than a conventional filter because of inadequate washing procedure. Intermixing of the two media was considered a serious detriment to the proper functioning of dual media filters. However Conley (15) have found that substantial mixing at the interface with these filters has a very favourable influence on head loss because the finer sand grains can not form an impervious mat when mixed with coarse anthracite.

CPHERI with the help of other organizations in
the coal field, made an intensive search to locate sources
of anthracite in this country so as to promote adoption of
two layer filtration in view of its potential application
in many of the existing over loaded plants (40). They also
investigated the suitability of indeginous high grade bitu-
minous coals. Their results indicate that indegenous good
quality bituminous coals would serve efficiently well as a
substitute for anthracite media. It was found out that
throughput could be increased by 50% with simultaneous
improvement in filtrate quality. It was also shown that the
increased output could be achieved at a cost much lower than
that would be required to construct an additional filter
bed of equivalent capacity.

2.6 DIFFICULTIES IN ADOPTING ABOVE MODIFICATIONS

When high rates of filtrations are used with
conventional filters, a number of difficulties are faced. The
clogging of top layer still remains a serious detriment
reducing the length of run considerably. It has also been
seen that average rate has been much lower than the design
rate (32, p. 86) Hoppins (45) said that it is a false
assumption to consider daily plant capacity equal to the
designed rating unless rate controlers are set at higher out-
put and the filter runs ended before the rates drop. It

has also been found difficult to control higher rates. A
coarse grained media can produce as clear water as could be
produced by fine grain filter. But it certainly needs
higher doses of chemical which will contribute to early
filter break through. The practical effect is that relatively
high alum feeds can not be tolerated if long filter runs
and high filter rates are necessary.

In case of upflow filters, although longer filter
runs are achieved, but the rate of flow is limited and is
even lower than the normal filters (Table 2.2). At high
rates there is a tendency of the bed to expand and finer
material at top may be lifted. It has also been seen that
back washing rates as well as duration has to be more while
we are considering economics, we have also to consider the
extra-mechanical arrangement made for reverse flow. It is
also doubtful whether such type of modification can be made
in a existing plant. It has also been stated (44) that upflow
filter will not be suited for higher turbidities. Similar
type of difficulties are also faced with biflow filtration.

About dual media filters it has been proved
beyond doubts that it is more efficient and economical.
The only problem remains with the availability of suitable
material. The suitability and economics should be
considered at the place.

2.7 SUMMARY

In the early years of the filter development most
of the work was oriented towards finding out the headloss
in the filter bed. Then attempts were made to represent
all filtration parameters in terms of mathematical equation.
Till today allmost all mathematical equations involve
impirical constants to be experimentally determined.
Importance of the mechanism of removal was also realised
and a great deal of work was done. The recent trend in the
filtration research has been the use of various modifications
to increase the efficiency of the filter. The research
has been experimental in nature and useful finding has been
made by filter operators. The use of multilayer filteration
which has definite advantages over other modifications has
become common in Europe and U.S.A. Lot of work has been
done to test this filter at various condition. In India
also search for suitability of a material has been made
which can successfully replace anthracite.

CHAPTER III

EXPERIMENTAL METHODS

3.1 APPARATUS AND EQUIPMENTS

a. Filter Column: Three inches diameter G.I.
pipe was taken to make filter columns. The diameter of
the column is sufficient to avoid wall effects as maximum
size of grain is 1 mm and 50 times the grain size is 5 cm,
which is the minimum size stated by Rose (43). The filter
column was 5' long, having a number 1/32" dia holes on both
sides, for connection to manometers and sampling etc.

b. Filter Bed: In case of column one, filter
bed consisted 15 cm cinder material passing through 18 B.S.
Sieve and retained on 25 B.S.Sieve. Below this was 48 cm
of sand passing through 25 B.S. Sieve and retained on 36 B.S.
Sieve. Second column consisted 63 cm of sand of same size
distribution. 30 cm of gravel pack was provided as a base
in both the columns. The gravel pack had top 2 cm between
1/8" to 1/4", 14 cm between 1/4" to 1/2" and 14 cm between
1/2" to 1". The details of filter column and filter bed is
shown in fig. 3.1 and 3.2.

c. Overhead Tank: Both the filter columns
and the overhead tank were arranged as shown in figure 3.1.
The overhead tank was made of a circular drum. It was 22"

in diameter and 28" long. The tank had an over flow pipe
connected at 6" from top. If over flow was desired. The
capacity of the tank was 131 litres.

    d. <u>Manometers</u>: Six, 1/4" diameter glass tubes
were used as manometers. The tubes were fixed on a board 8'
long. These tubes were connected to brass tappings of the
filter columns by polythene or tubes. The tapping on the
other side of the filter columns were used for taping out
samples from the filter.

    e. <u>Feed Suspension</u>: Kaolinite ($Al_2Si_2O_5(OH)_4$)
was used to prepare feed suspension. The Kaolimiti was
dried before use. A suspension of known concentration
(10,000 mg/l) was prepared and was fed to the overhead
tank from a bottle to keep the concentration in the overhead
tank constant at 100 mg/l.

    f. <u>Coagulant</u>: Analytical reagent grade potash
alum. $Al_2(SO_4)_3 \cdot K_2SO_4 \cdot 24H_2O$ was used as a coagulant. The
solution was prepared in distilled water. Two separate
bottl s were kept above the overhead tank to feed alum
solution through the brass tapping provided in the filter
column.

    g. <u>Water</u>: Institute tap water was used to
prepare turbidity solution.

h. Spectrophotometer: Bauch and Lomb spectromic 20 was used to measure the turbidity of the samples. The wavelength used for determination was 390 milli micron and cylindrical cell of 1 cm dia. was used.

3.2 EXPERIMENTAL PROCEDURE

3.2.1 RATE OF FLOW CONTROL

Rate of flow control is done at two places, one is for the flow through the filter and another flow into the overhead tank. Rate of flow of tap water into the overhead tank was controlled with the help of the valve no.V6 (Fig. 3.1). Flow of this water could be measured by passing the flow through over flowing pipe. For 2 gpm flow, this was adjusted to be 1 litre per min. The turbidity feed from the bottle was adjusted to this flow. This is little more than what is required flow through filters. For 2 gpm flow through each filter has to be adjusted to 450 ml/min. This will mean a overflow of 100 ml/min from the overhead tank. Therefore measurement of continuous overflow in addition to the flow through the filter gave a check for the water flowing into the overhead tank. Flow through the filters was adjusted with the help of the valves no. V4 and V5 provided at the bottom of the filter.

3.2.2 PREPARATION OF TURBID WATER

A constant head bottle having a feed suspension

of 10,000 mg/l was kept above the over-head tank. Initially
13.1 grams of Kaoline was added in the drum since the capa-
city of the drum was 131 litres. This gave 100 mg/l turbidity
in the drum. Adjusted amount of turbidity was added in the
tank from the bottle. The flow of turbidity was regulated
with the help of screw cock provided at the air inlet tube
to the bottle. This avoided the chocking of tube at pinch
cock. To prevent the settlement of turbidity, the bottle
was shaked once in 30 minutes and turbidity of the tank was
checked every hour.

3.2.3 METHOD OF ALUM INTRODUCTION

Two constant head bottles having alum solution of
1000 mg/l were kept above the overhead tank. The screw cock
was adjusted and flow after every hour was checked with the
help of amount of solution which has gone out of the bottle.
Long rubber tubes were used with one end fitted to the brass
tapping and other end with the alum feed bottle. Alum
solution was fed at 9 cm below the top of the bed. Rate
of flow of alum solution was maintained in order to provide
10 mg/l of alum to the turbid water.

3.2.4 METHOD OF BACKWASH

In figure 3.2 valve no. V_3 was closed first and
all other opened. The bottom of the filter was directly
connected to the tap. The used water in back wash was

coming out through the overflow tube. When the this water
was found to be clear the backwashing was stopped. Similarly
the second filter was cleaned by closing valve no. V2.

3.2.5 EXPANSION DURING BACKWASH

It was not possible to see the expansion of beds
during backwash in the G.I. pipe filter. It was found
important to know the difference in expansion between the
sand and the cinder. Therefore a seperate glass filter was
packed with 17 cm. of sand and 8 cm of cinder. Various flow
rates were used to know the relative expansion.The On inter-
mixing of the media, which could also be seen through the glass
column.

3.2.6 FILTER RUNS

Following is the sequence in which various
adjustments should take place. Before the experiment is
started the first adjustment is made with alum solution flow
into the filter and once it is set, the flow is constant
throughout the experiment. For the continuous preparation
of turbid water valve no. V6 (Fig. 3.2) is controlled to
have a required flow of water into the tank. Now the valve
V4 and V5 are operated to make the flow through the filter
to be 2, 3 or 4 g.p.m. as required. For the adjustment of
flow of turbidity from stock suspension to the overhead
tank required number of drops per minute is known before

hand and the flow is adjusted with the help of stopwatch by counting number of drops per minute. Three manometer tubes are connected to the first filter and other three to the second one. Care is taken so that air bubbles are not entrapped. Turbidity samples are taken and at the same time water level in the manometers is recorded. After every 30 minute, the turbidity feed bottle and turbid water in the overhead tank is shaked. Flow through the filters is checked at every hour.

3.3 DETERMINATION PROCEDURE

3.3.1 EFFECTIVE SIZE OF SAND AND CINDER

The effective size and uniformity coefficient of sand and cinder were found by sieve analysis. The sand which passed through 25 BSS and was retained on 36 B.S.S. was used in the filter. A known quantity was kept in a shaper containing a set of B.S. Sieves. The sieves used were 25, 36, 52 and 100. After 10 minute of shaking, the amount of sand retained on each sieve was weighed. The cinder used was passed through 18 B.S.S. and was retained on 25 B.S.S. The sieves used for sieve analysis were 18, 25, 36 and 52. By plotting these values on a semi-log paper the uniformity coefficient and the effective size of sand were calculated.

3.3.2 SPECIFIC GRAVITY OF SAND AND CINDER

Constant volume method has been utilised for the

determination of specific gravity. A weighed quantity of
sand or cinder put into the pycnometer bottle and water is
filled up to mark and weighed. Then only water is put into
the bottle and weighed. Let

Weight of pycnometer bottle, sand and water = W_1

Weight of pycnometer bottle with water = W_2

Dry wt. of sand or cinder = W_s

If specific gravity of water is unity specific gravity of
sand or cinder

$$= \frac{W_s}{W_s - W_1 + W_2}$$

3.3.3 SOLUBILITY OF CINDER IN DILUTE HCl

American water works association, New York in "Tentative
Standard Specifications for Filtering Material" has specified
that filter material should not lose more than 5 percent
by weight after being placed in 40 percent hydrochloric acid
for 24 hours. Sand is insoluble in hydrochloric acid. The
test was performed for cinder. Cinder contains ash material
with it which is quickly washed off by water as much of that
material is lighter than water. Therefore a well washed sample
of cinder was dried, weighed and put in 40 percent HCl.
It was again washed dried and weighed percent loss was
calculated.

3.3.4 DETERMINATION OF TURBIDITY

Determination of the turbidity was made by measuring the absorbance of light by B and L spectromic 20. The optimum wavelength giving the maximum absorbance was found to be 390 milli micron. First a standard curve was prepared by measuring absorbance at known concentration of turbidity and the curve was plotted. This curve was used to find the turbidity of the samples.

3.3.5 HEAD-LOSS MEASUREMENT

Tappings have been provided at various points throughout the depth of the filter. As the manometer is connected to any point, the difference between the total head available and the water level in the tube gives the headloss at that point.

EXPERIMENTAL SET-UP

A & C ALUM FEED BOTTLES
B – TURBIDITY FEED
V – VALVE

OVER FLOW

STORAGE TANK

BACKWASH WATER

V1

V2

V3

V6

Col. 1

Col. 2

TAP WATER

CONNECTED TO TA

V4

V5

MANOMETER TUBES
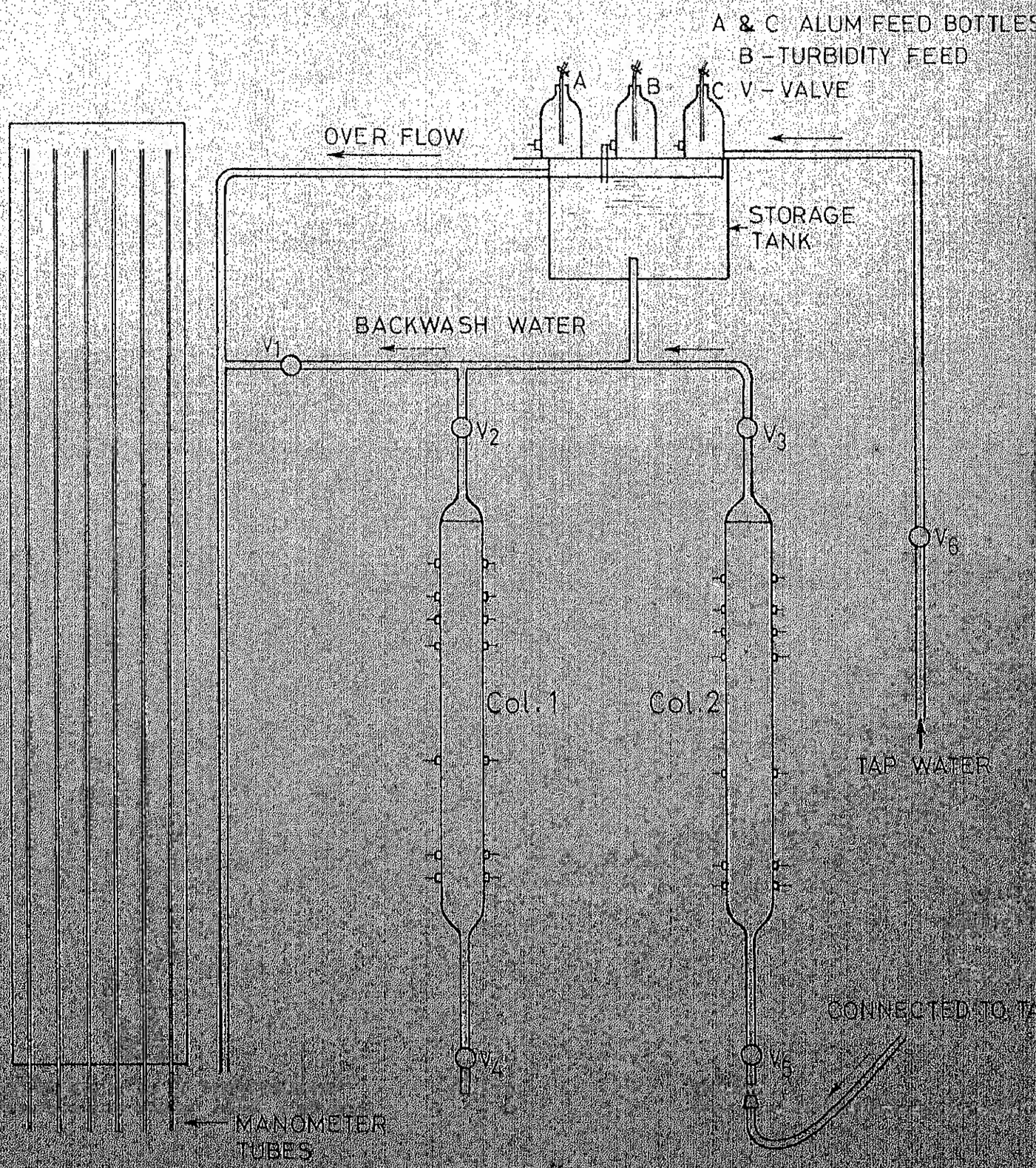
FIG. 3.1

DETAILS OF FILTER BED

Column-1

Column-2

A — CINDER
B — SAND
C — GRAVEL(1/8–1/4)
D — GRAVEL(1/4–1/2)
E — GRAVEL(1/2–1)
F — WIREMESH
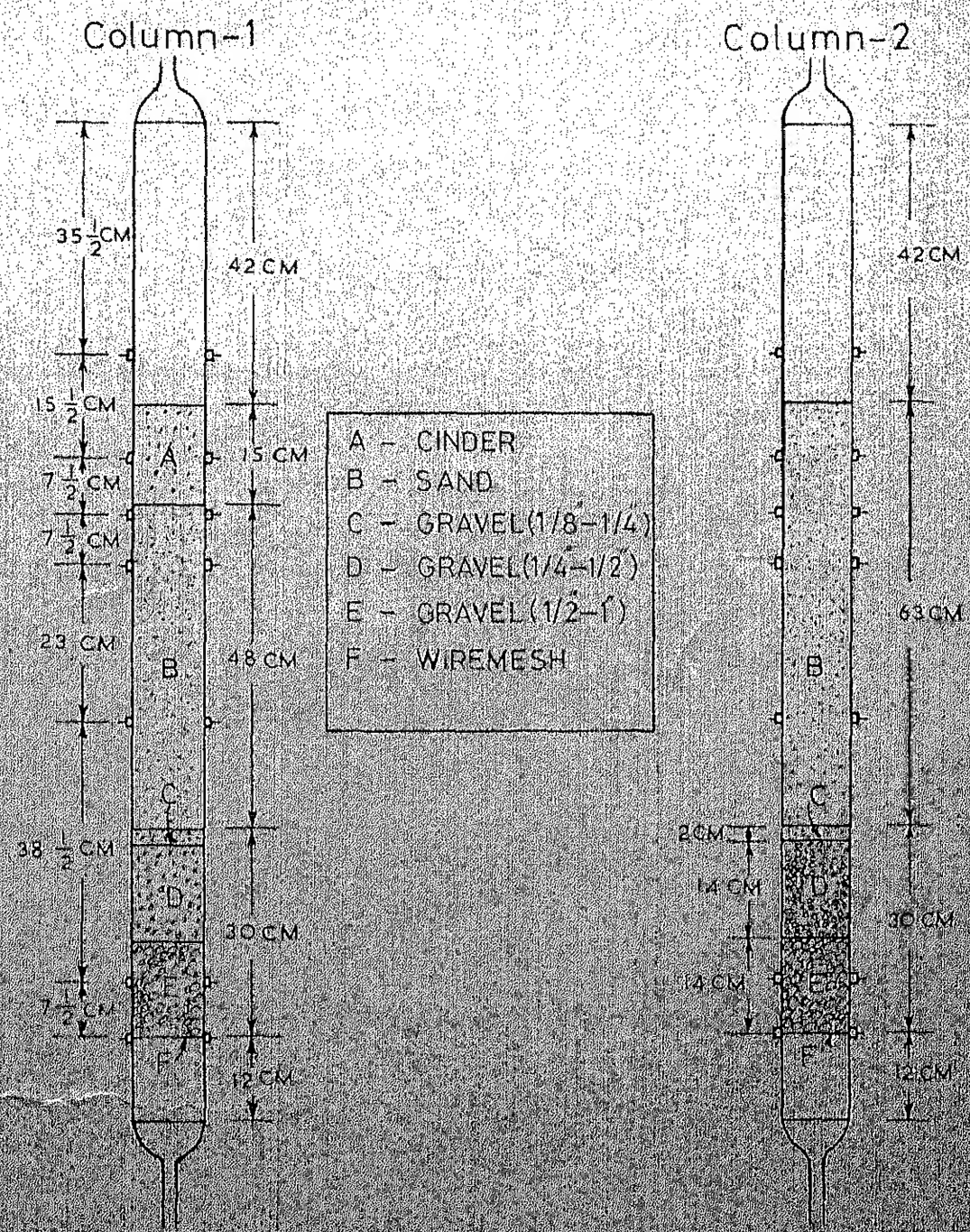
FIG. 3 2

CHAPTER IV

EXPERIMENTAL RESULTS

4.1 MEDIA PROPERTIES

a) grain size (Table A.2, A.3)

	Effective size	Uniformity coefficient
Sand	0.45 mm	1.26
Cinder	0.68 mm	1.24

b) Specific gravity (Table A.4)

specific gravity of sand = 2.65

specific gravity of cinder = 1.17

c) Solubility of cinder = 0.49% (Table A.5)

d) Percentage expansion (Table A.6)

Rate of backwash (cm/min)	40	60	80	100
Cinder	18.5	32.5	46.0	59
Sand	11.5	23.0	34	45.5

4.2 CHARACTERISTICS OF INFLUENT WATER

a) Analysis of tap water

pH	8.3
Alkalinity	540 mg/1 as $CaCO_3$
HCO_3	540 mg/1 as $CaCO_3$
Hardness (Total)	200-220 mg/1 as $CaCO_3$
Ca^{++} Hardness	180-190 mg/1 as $CaCO_3$

SO_4^{--} 40 mg/1

Total solids   680 mg/1

b)   Turbidity in influent water

Colloidal particles - Kaolinite

Amount   -   100 mg/1

4.3   FILTER RUNS

	COLUMN-1	COLUMN-2
Media used	Cinder-Sand	Sand alone
FLOW - 2 gpm		
% turbidity removal at 10 Hrs.	100	100
% turbidity removal at the end of run	100	100
Length of run* (hr)	43	31
FLOW - 3 gpm		
% turbidity removal at 20 Hrs	100	100
% turbidity removal at the end of run	67	100
Length of run* (Hr.)	30	25
FLOW - 4 gpm		
% turbidity removal at 4 Hrs.	100	100
% turbidity removal at 8 Hrs	83%	83%

	COLUMN-1	COLUMN-2
% turbidity removal at the end of run	16%	50%
Length of run* (Hr.)	20	15

* Length of run is time of run at the headloss of 150 cm., however if turbidity values for effluent are higher the length of run should be decided by the time for 99.5% removal.

4.4 THEORETICAL VALUES OF HEAD LOSS AND SETTLING VELOCITY

a) Settling velocity

The Stoke's law for settling velocities gives following equation

$$v_s = \frac{4}{3} \cdot \frac{g}{C_D} (S_s - 1)d \qquad 4.1$$

$$C_D = \frac{24}{R} + \frac{3}{R} + 0.34 \qquad 4.2$$

where

v_s = settling velocity

g = acceleration due to gravity

S_s = specific gravity of cinder or sand

d = dia of particle

R = Reynolds number

	Dia. of particle (cm)		Specific gravity
Sand	0.30×10^{-1}	0.55×10^{-1}	2.65
Settling velocity (cm/sec.)	2.70	3.54	
Cinder	0.45×10^{-1}	0.80×10^{-1}	1.17
Settling velocity (cm/sec.)	0.35	0.47	

b)   For a clean filter following equation has been drived from equations 2.8 to 2.11 considering flow to be laminar

$$\Delta h/\Delta \ell \;=\; 25.6 \cdot \frac{v}{g} \cdot \frac{v}{f^4} \cdot \frac{1}{d^2} \qquad\qquad 4.3$$

For sand

$$\Delta h \;=\; 0.039 \times 10^{-2}\, \Delta \ell \,\frac{Q}{d^2} \qquad\qquad 4.4$$

For cinder

$$\Delta h \;=\; 0.0256 \times 10^{-2}\, \Delta \ell \,\frac{Q}{d^2} \qquad\qquad 4.5$$

where

$$Q \;=\; \text{flow gpm/dt}^2$$

COLUMN 1

Depth (cm)	Dia. of grain (cm) d	Headloss (cm) h Q = 2 gpm	Headloss (cm) h Q = 3 gpm	Headloss (cm) h Q = 4 gpm
1	0.030	0.84	1.26	1.68
5	0.040	2.37	3.55	4.74
5	0.045	1.87	2.82	3.74
9	0.050	2.74	4.10	5.48
43	0.055	10.80	16.20	21.60
	TOTAL	19.62	27.83	39.24

COLUMN 2

Depth (cm)	Dia. of grain (cm) d	Headloss (cm) h Q = 2 gpm	Headloss (cm) h Q = 3 gpm	Headloss (cm) h Q = 4 gpm
1 (Cinder)	0.045	0.25	0.37	0.50
4 (Cinder)	0.065	0.48	0.72	0.96
10 (Cinder)	0.080	0.79	1.19	1.58
5 (Cinder)	0.045	1.87	2.80	3.74
8 (Cinder)	0.050	2.43	3.65	4.86
35 (Cinder)	0.055	8.80	13.20	17.60
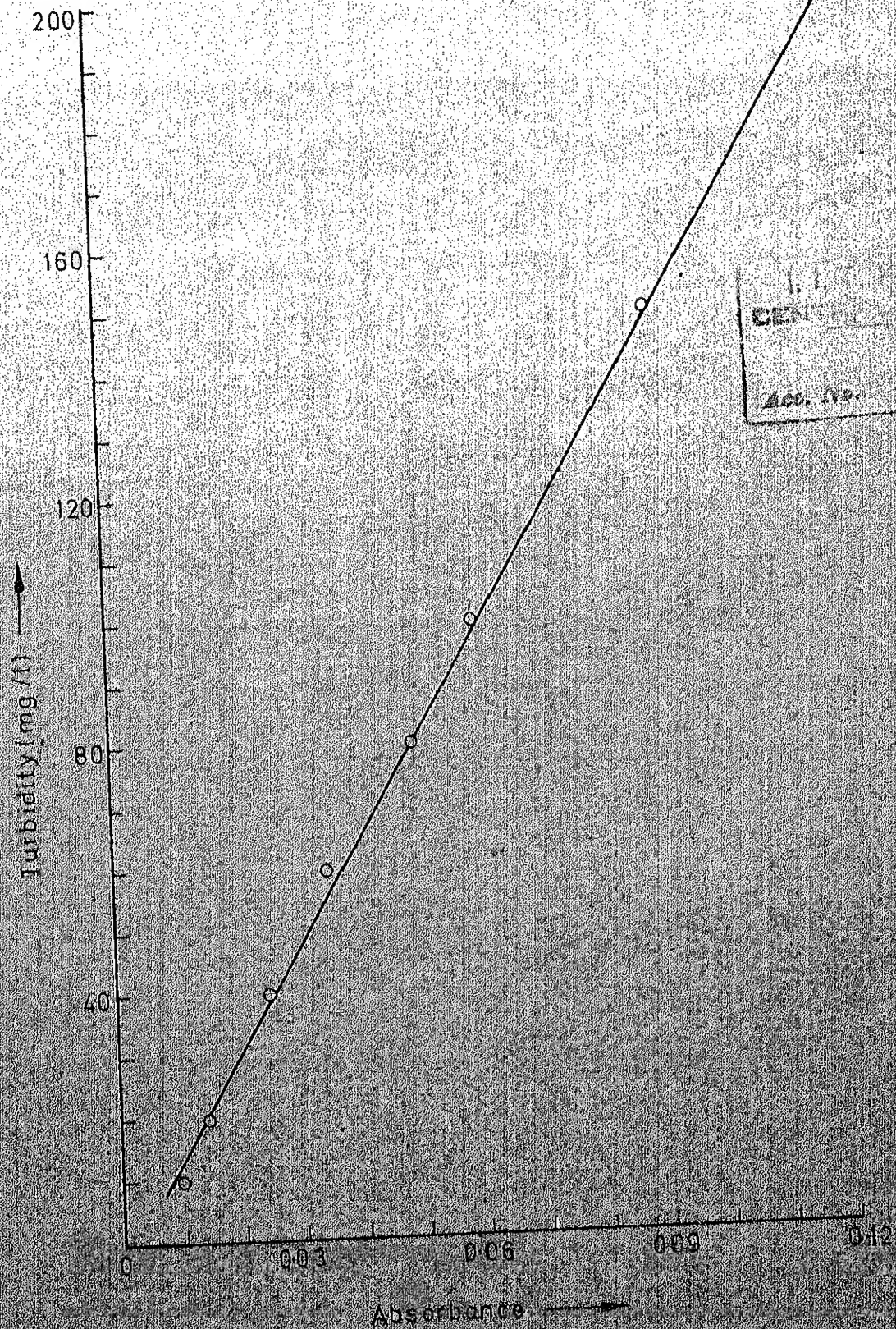
FIG 4.1: STANDARD CURVE BETWEEN TURBIDITY AND ABSORBANCE

SIEVE ANALYSIS OF SAND

SIEVE ANALYSIS OF CINDER
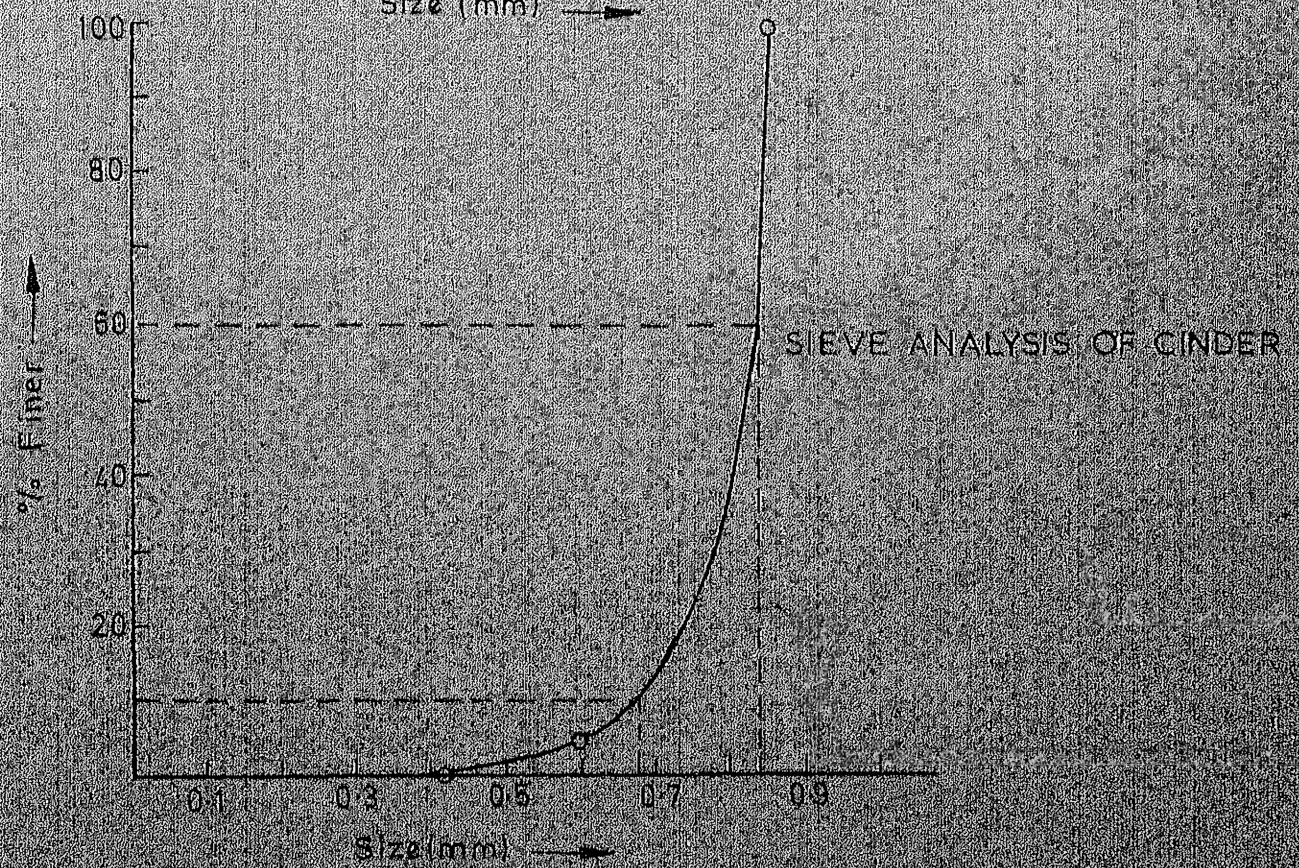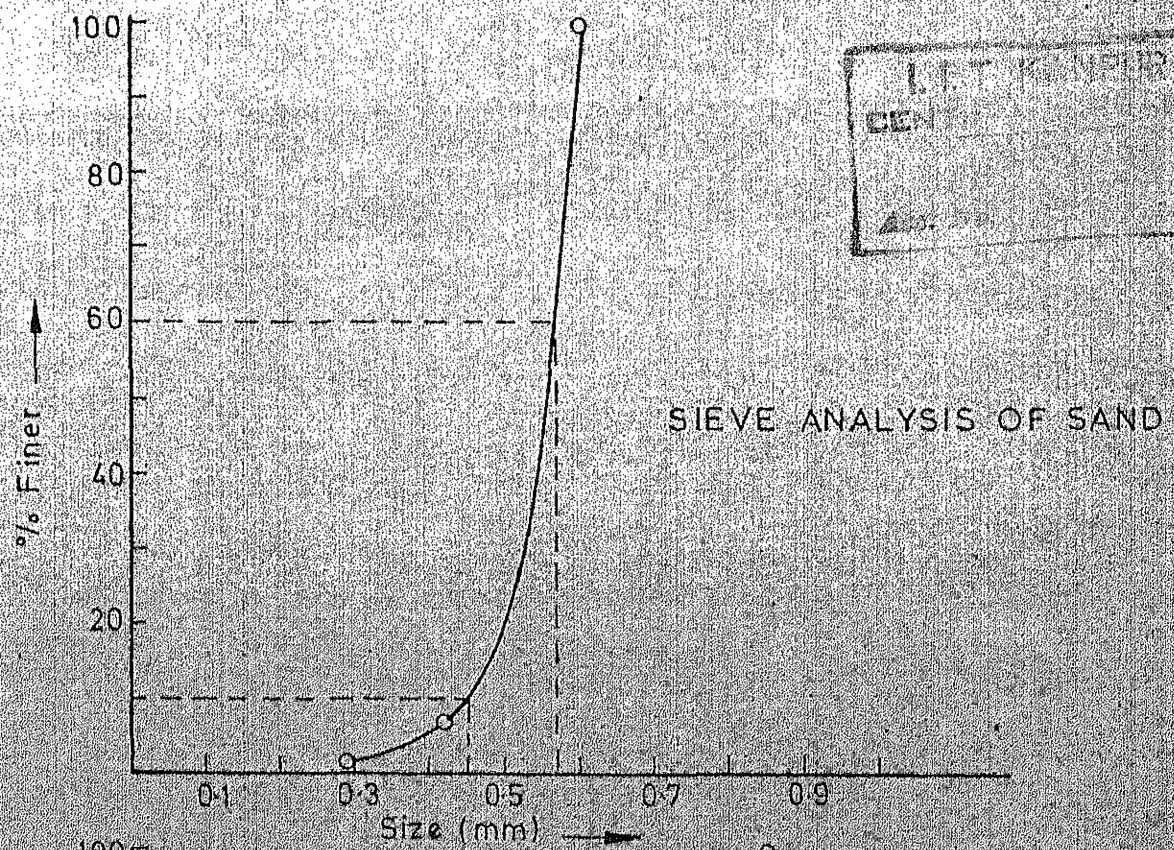
FIG. 4·2
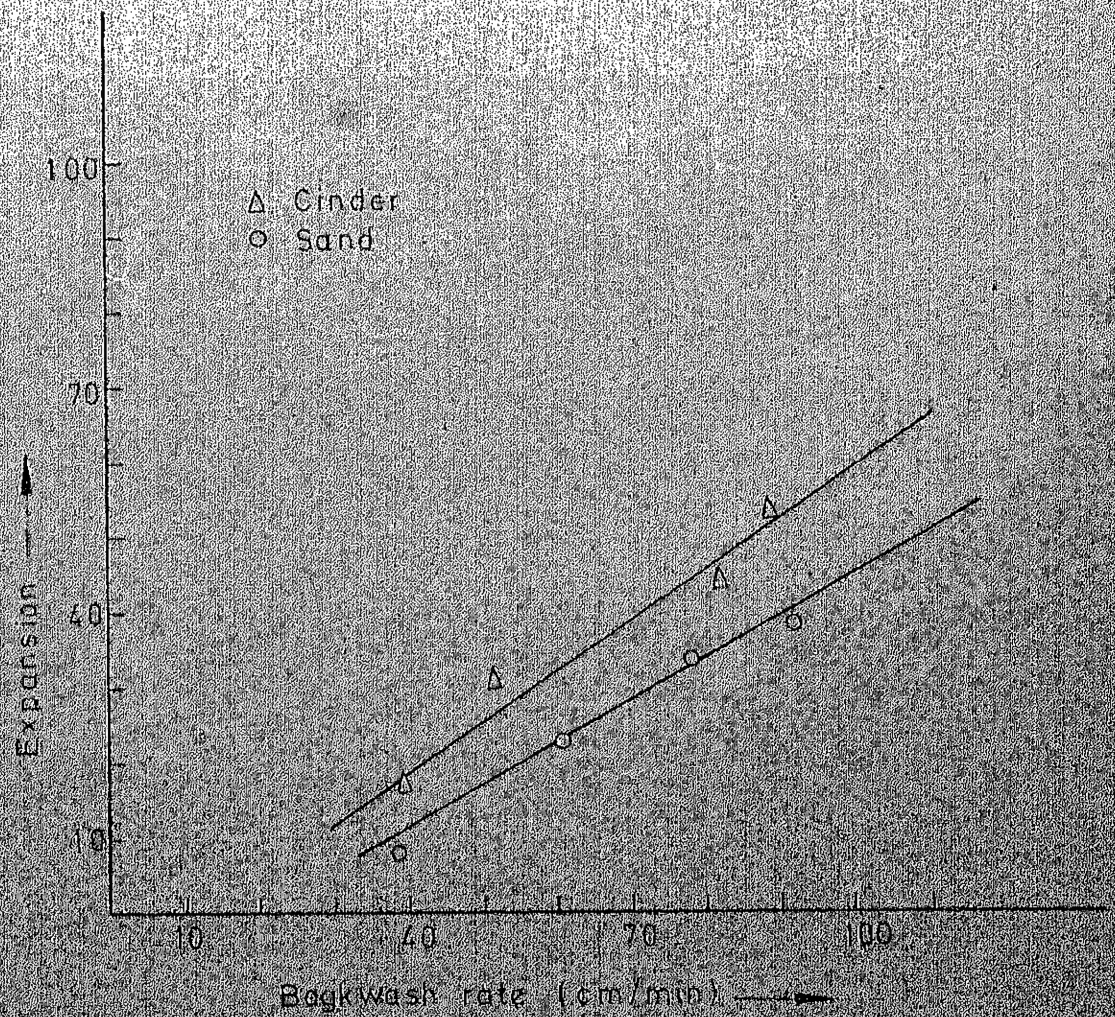
FIG. 4.3 RELATIVE EXPANSION OF SAND AND CINDER

Flow - 2 gpm/ft²

Headloss (cm)

Depth (cm)
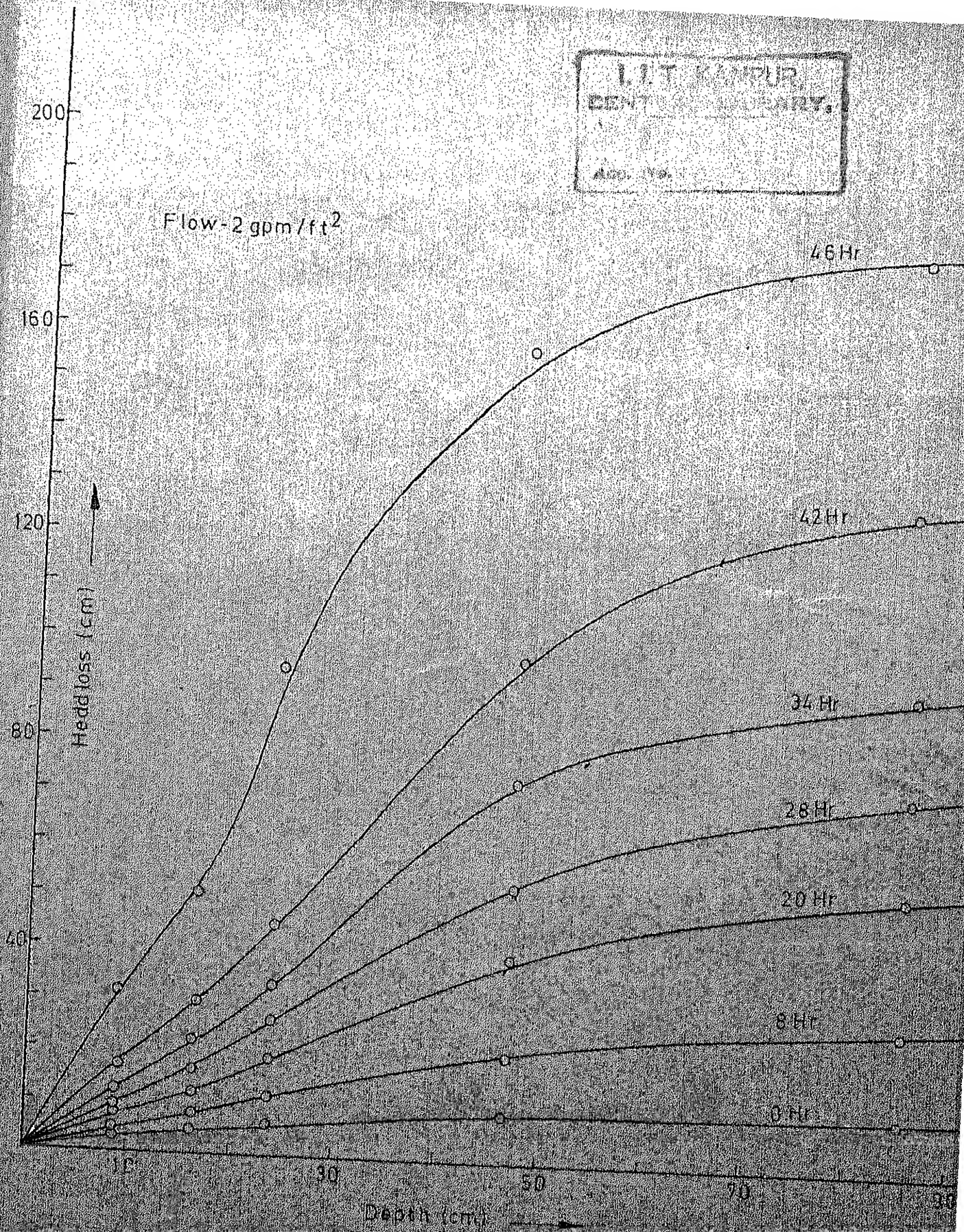
FIG. 4·4 HEADLOSS VS DEPTH FOR VARRYING TIME
(COLUMN 1)

FIG. 4.5 HEADLOSS VS DEPTH FOR VARRYING TIME
(COLUMN 2)

Flow-2gpm
—o— Column-1
—Δ— Column-2

Time (Hr)

FIG-4.6 HEADLOSS Vs TIME

FIG. 4·B TURBIDITY VS DEPTH FOR VARYING TIME
(COLUMN 2)
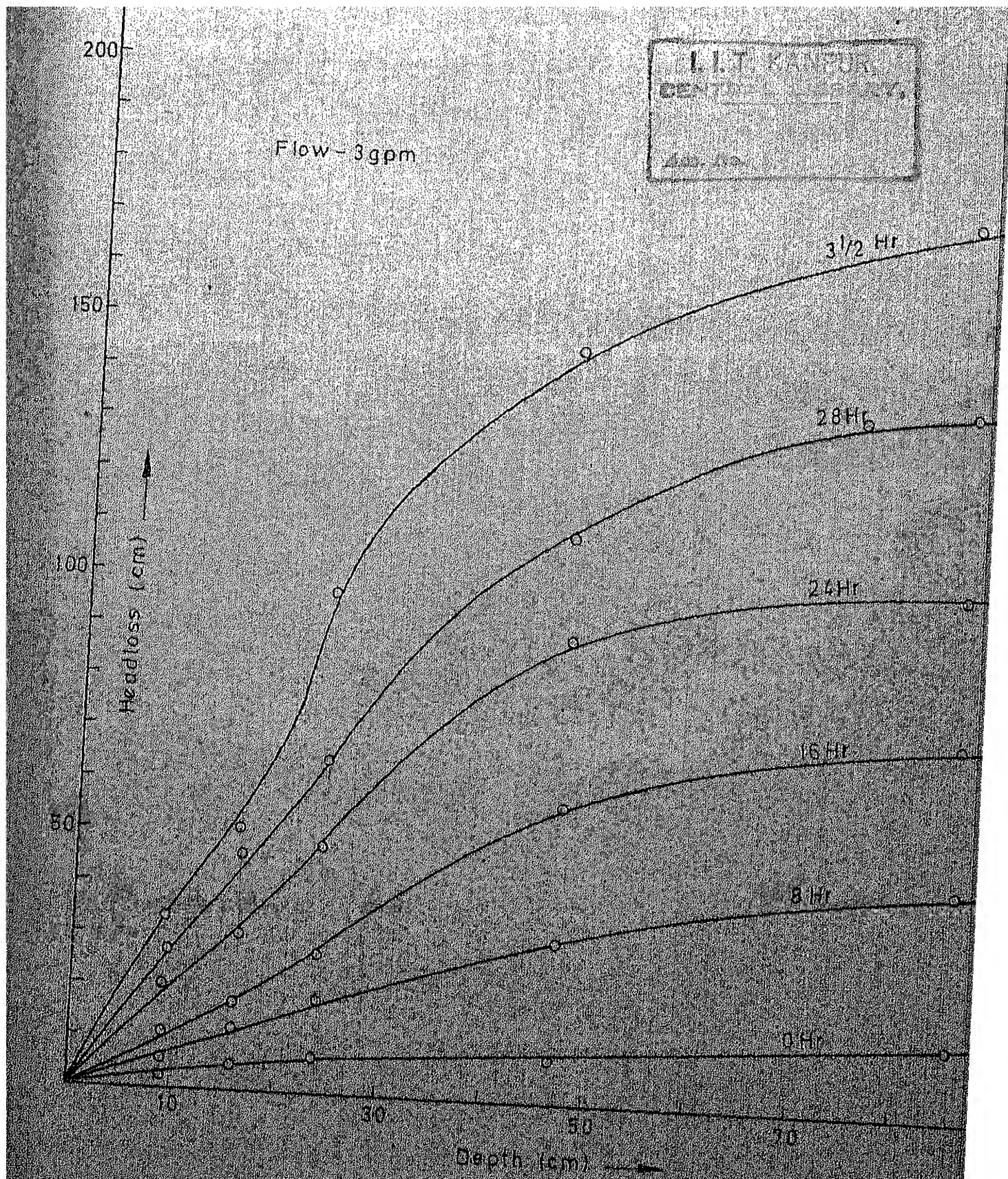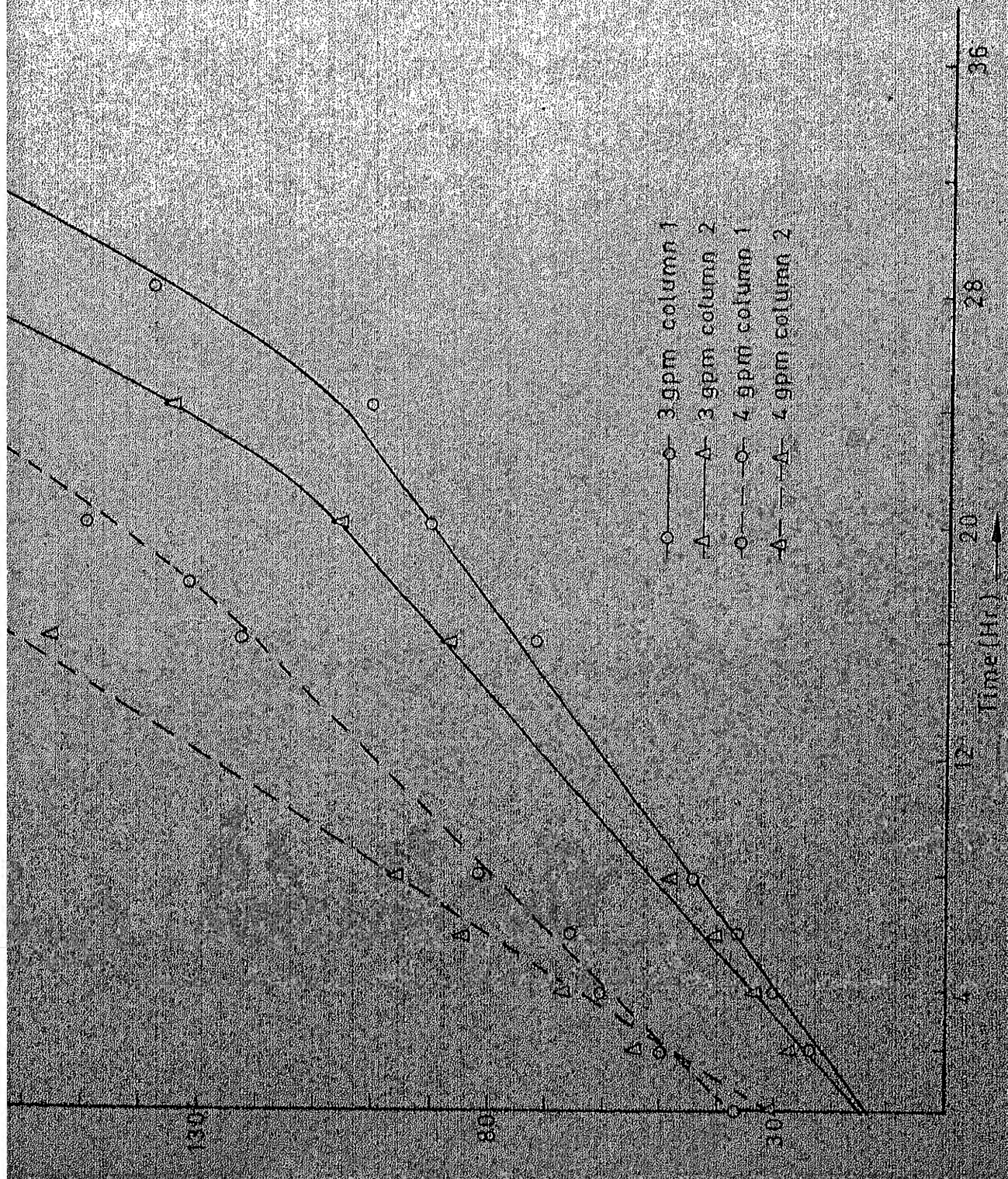
FIG 4.9 HEADLOSS Vs DEPTH FOR VARRYING TIME (COLUMN 1)

FIG. 4.10 HEADLOSS VS DEPTH FOR VARRYING TI
COLUMN 2

FIG. 4.11 HEADLOSS VS TIME

Legend:
—○— 3 gpm column 1
—△— 3 gpm column 2
–○– 4 gpm column 1
–△– 4 gpm column 2

Time (Hr.)

TURBIDITY VS DEPTH
(COLUMN-1)

Flow - 3 gpm

TURBIDITY VS DEPTH
(COLUMN-2)

Flow - 3 gpm

FIG. 4.12

Flow - 4 gpm

TURBIDITY Vs DEPTH
(COLUMN-1)

Flow- 4 gpm

Turbidity (mg/l)

24 Hr
20 Hr
16 Hr
8 Hr
4 Hr

TURBIDITY Vs DEPTH
(COLUMN-2)

Flow- 4 gpm

Turbidity (mg/l)

18 Hr
16 Hr
8 Hr
4 Hr

10   30   50   70   90 95
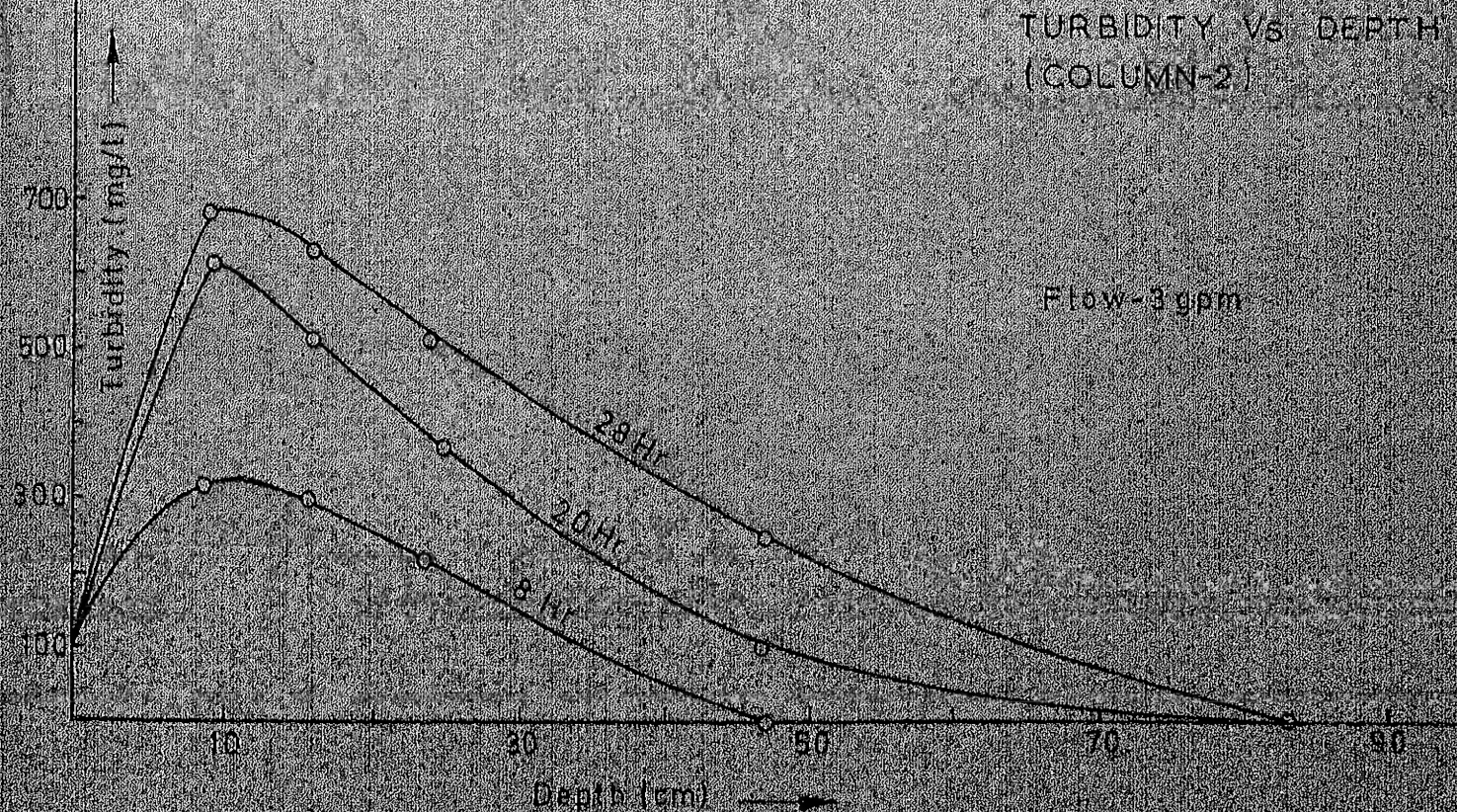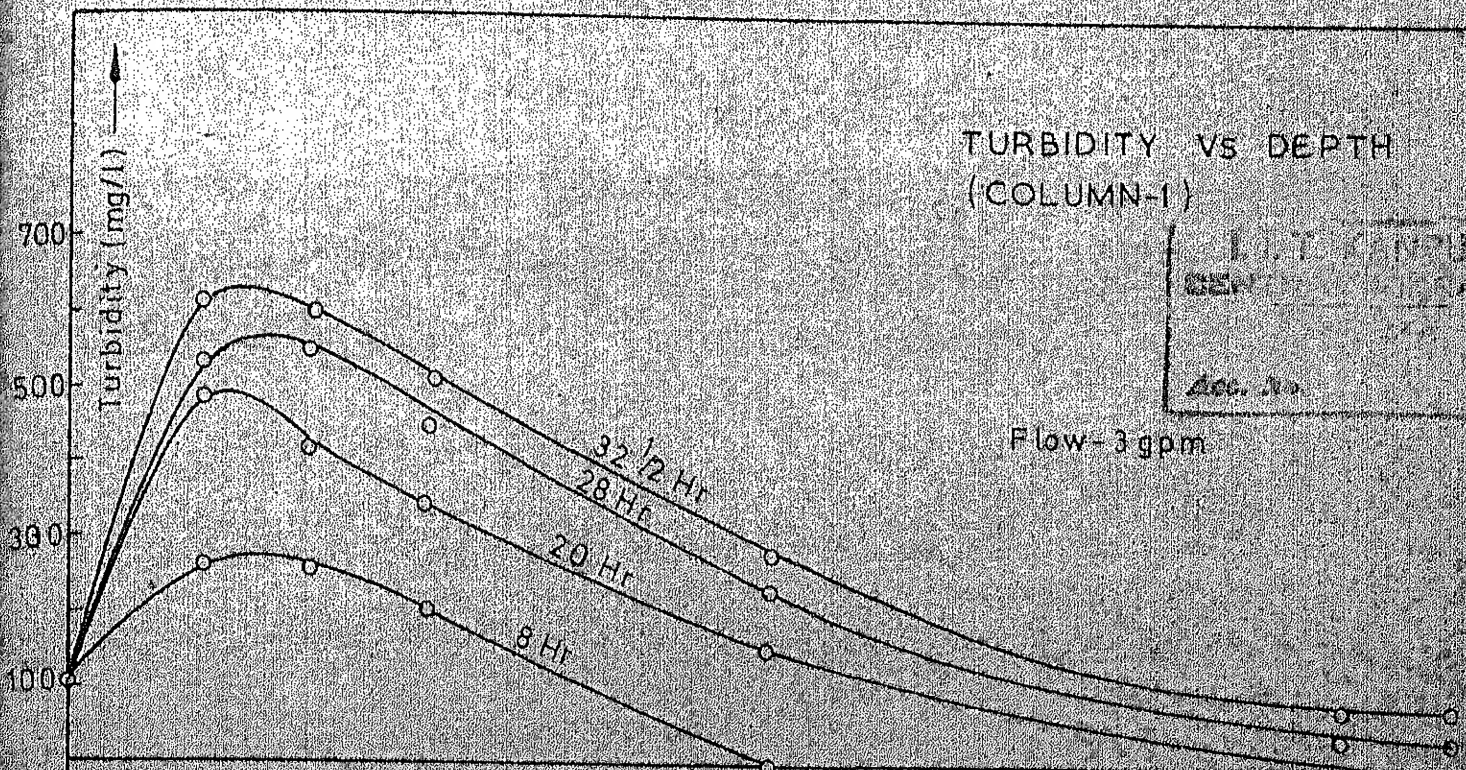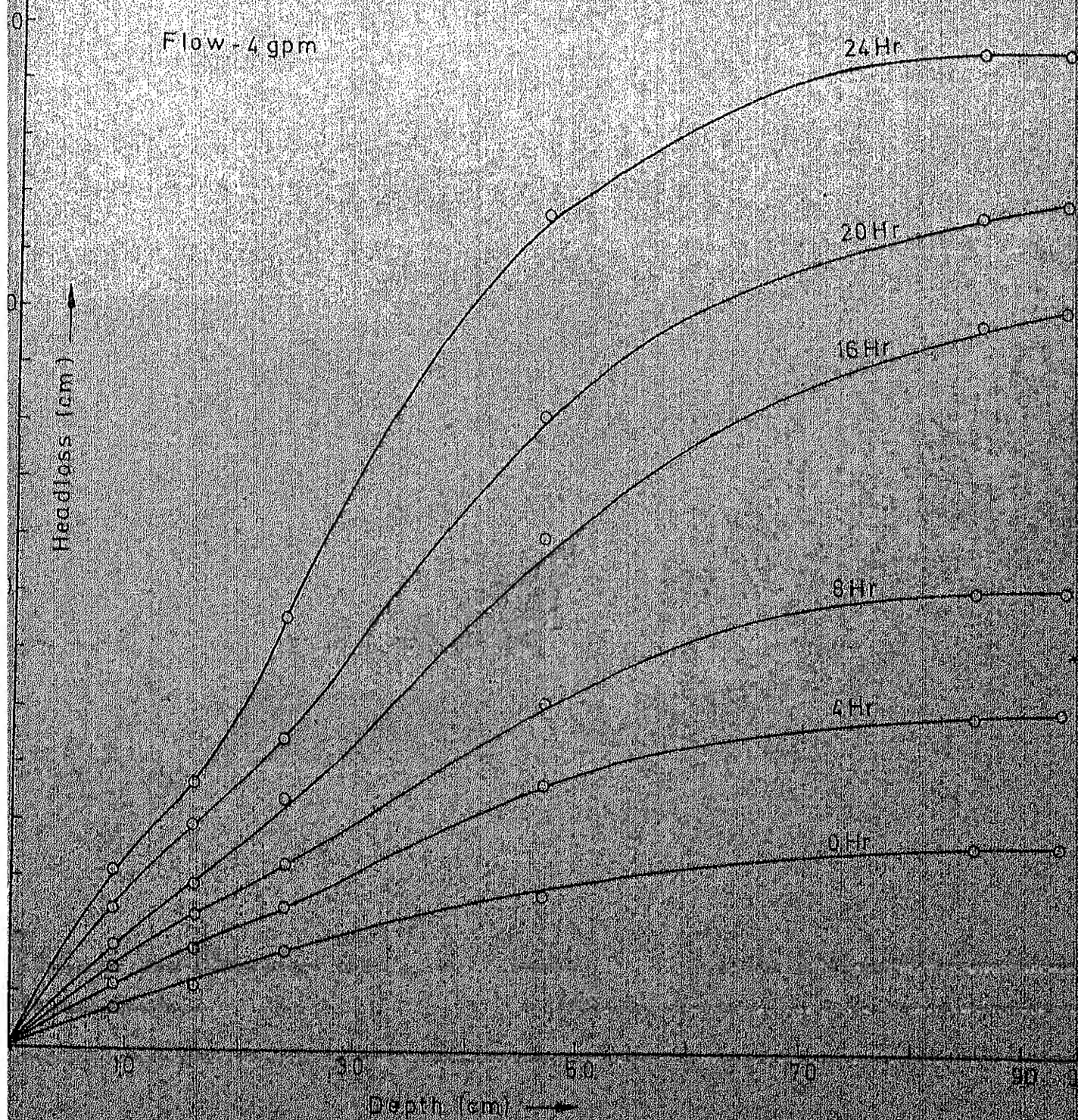
Depth (cm)
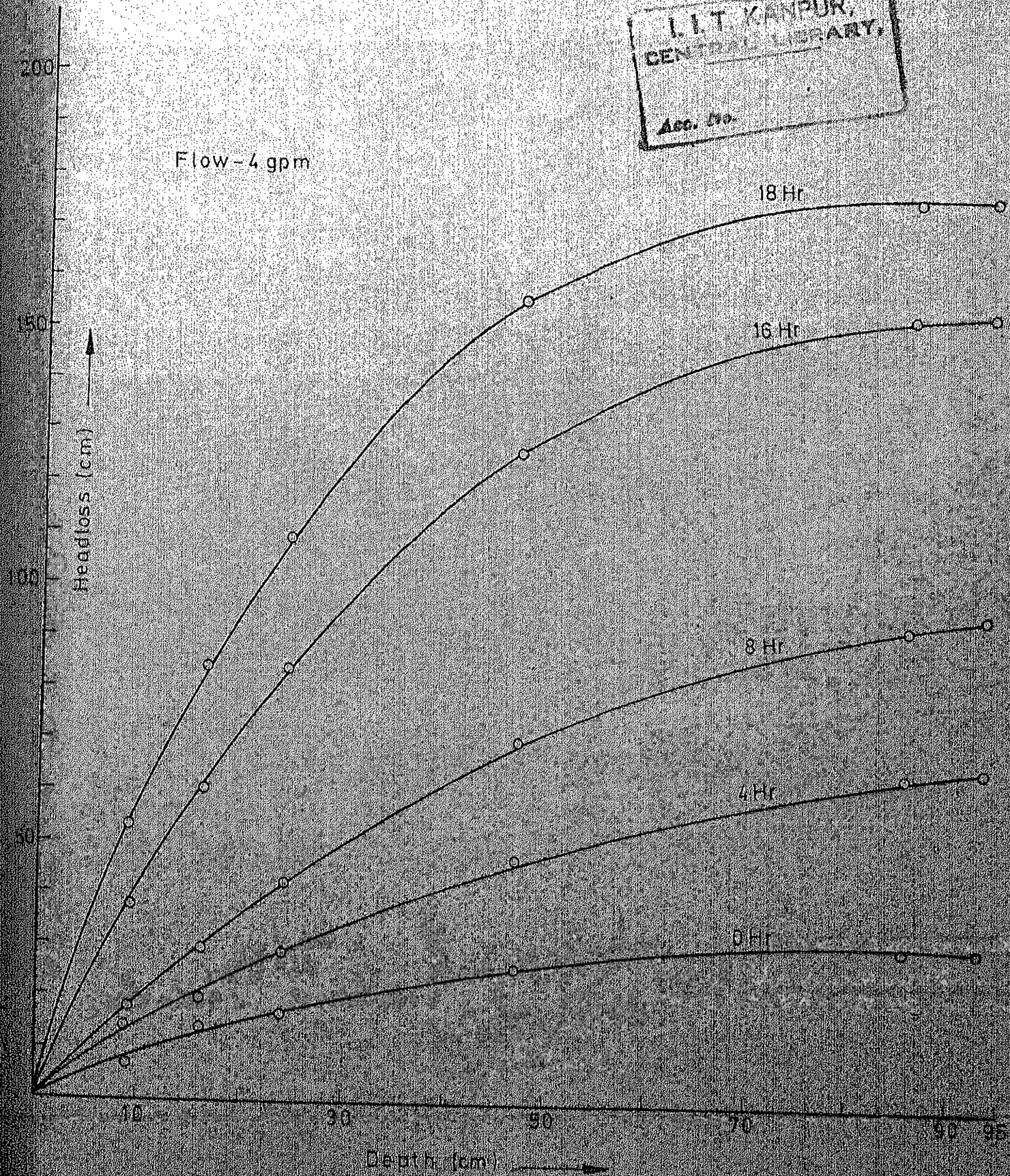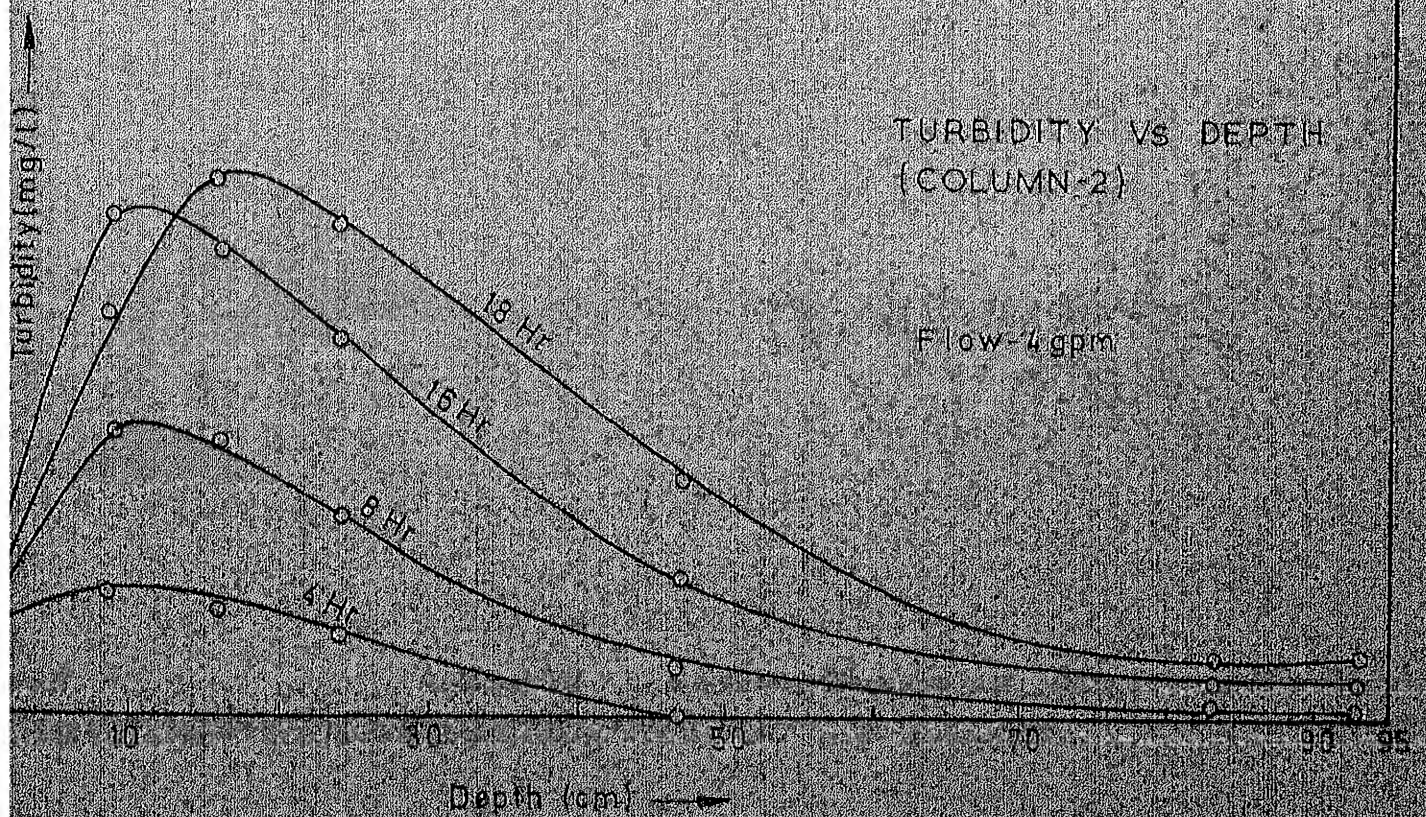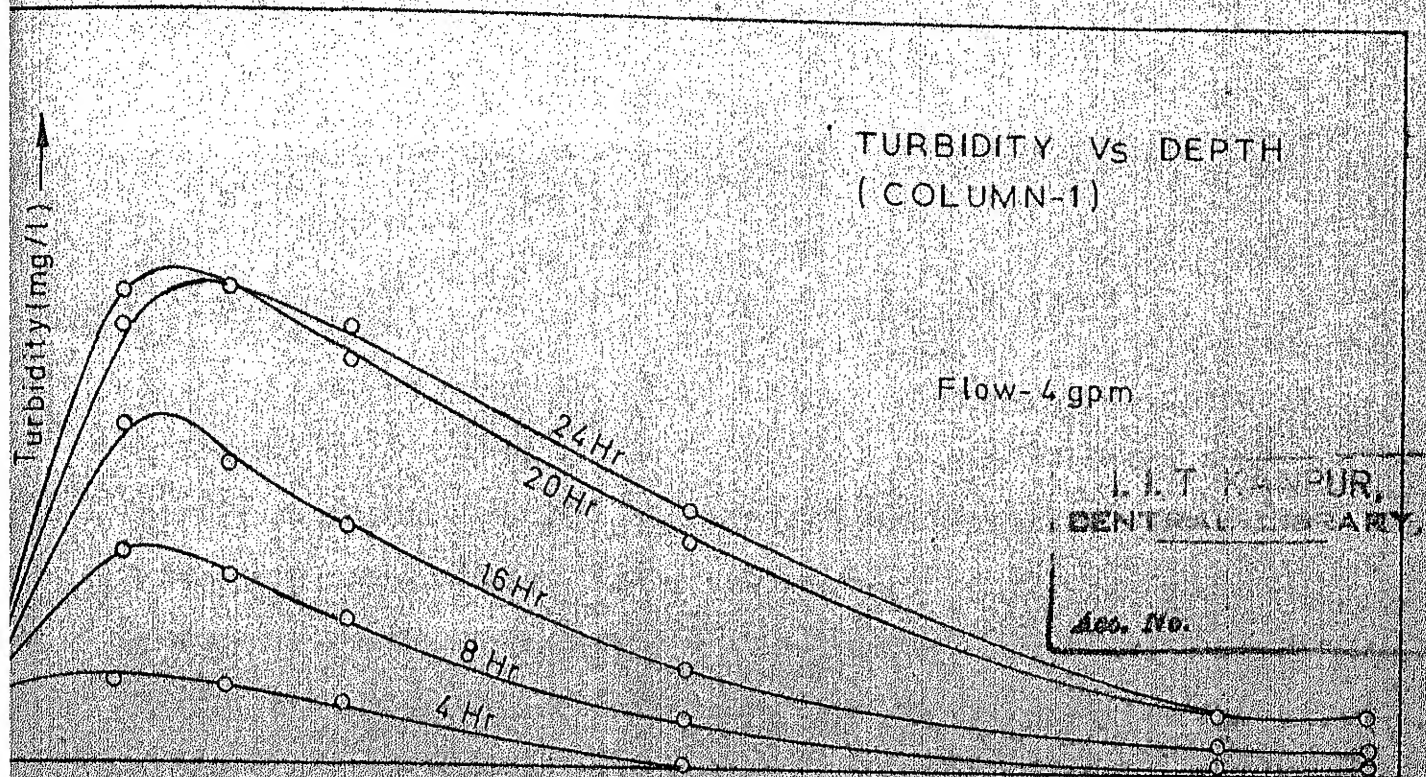
CHAPTER V

DISCUSSION

5.1 FILTER RUNS WITH CONVENTIONAL GRADED SAND FILTER

In the present study column 2 essentially represents a conventional graded filter in which a single material sand having uniformity coefficient of 1.27 and effective size of 0.45 mm has been used. After the backwash which fluidizes the whole depth of sand, there is a definite arrangement of different sizes of sand particles. The finest material remains at top leaving coarsest at bottom and filter is said to be graded. Using a flow of 2 gpm/ft^2 and alum dose of 10 mg/l, the headloss and turbidity curves have been plotted as shown in figure 4.5 and 4.8 respectively from which we can observe as follows.

5.1.1 INITIAL HEADLOSS IN A CLEAN FILTER

When there is no floc deposited in the bed the headloss is only due to the obstruction provided by sand grains. The headloss at zero hour is only due to this head-loss. For the depth beyond 20 cm the curve is a straight line which is expected for the uniform sand bed. The grain size distribution (Fig. 4.2) also supports this. If the whole bed is divided into number of layers containing different sand size and Equation no. 4.1 is used to calculate the

headloss, it is found that headloss pattern is similar to

The headloss vs depth curve for 8 hrs beyond the depth of
24 cm is thus almost a straight line parallel to the zero
hour curve. The slight variation in the curve from the
straight line might be because of some small amounts of
turbidity still reaching and being arrested by lower layers.

Even up to a period of 20 hrs only half of the
bed is utilized and depth of floc penetration is 47 cm.
Although turbidity moves down to the lower layers after the
saturation of previous layer, but the deposition still con-
tinues in upper layers. At 28 and 34 hours, although the
floc penetration is deep and the headloss pattern shows floc
distributed in the whole depth of bed, but a larger portion
of the headloss and turbidity removal still occurs in the
top layers of the bed. About 83% of the headloss occurs in
the upper half of the bed at 8 hours and for 34 hours this
percentage becomes 98%. This means lower half depth of the
column is almost unused and this is uneconomical.

5.1.3 HEADLOSS VARIATION WITH TIME

The total headloss in first 8 hours is 40 cm and
the same for next 8 hours is also 42 cm. This means as time
passes on rate of headloss increase is not much changed.
This is consistant with equation 12 given by Deb (23).
The headloss is approximately proportional to the specific
deposit. Specific deposit which is volume of deposit per
unit volume of filter media, increases with time linearly.

A curve is plotted between headloss and time, it is seen
that curve is a straight line upto a period of 20 hours.
After this headloss increase rate is more. The headloss in
last 8 hours is 60 cm. This nonlinearity of headloss time
curve is only seen with total headloss andiif lower depths
are considered such as 10 and 20 cm the rate of headloss
increase is constant with time again showing that lower
layers stay more or less unused.

5.1.4 TURBIDITY VARIATION WITH DEPTH

Turbidity values with depth have been plotted for
varying time in Fig. 4.8. These curves also support that
depth of penetration of floc increases with time. At 2 hour,
turbidity beyond 16 cm is zero and for 8 hours this depth
becomes 24 cm. Even upto 20 hours the removal is only due
to half depths.

Turbidity first increases with depth, reaches a
maximum and then decreases to a minimum value. This is
because alum addition is made in the bed 9 cms below the top
of bed. Floc formation takes some time and up till that
time there is not much obstruction to the flow of water. The
floc formation decreases the rate of flow of water and hence
turbidity is accumulated at certain depth in the bed. This
increase in turbidity is not reflected by headloss curve
in any way and headloss curve is smooth for all depths.

5.2 FILTRATION RUNS IN DOUBLE LAYER FILTER WITH 15 CM OF CINDER

In column 1, the 63 cm of sand bed is replaced by 48 cm of sand and 15 cm of cinder. The preliminary test showed that cinder because of its lower density will settle over the sand bed after the backwash, although there is small depth containing both materials. The cinder has the effective size of 0.68 mm and a uniformity coefficient of 1.24. Using a flow of 2 gpm/ft^2 and alum dose of 10 mg/l, the headloss and turbidity curves have been plotted as shown in Fig. 4.4 and 4.7.

5.2.1 HEADLOSS DISTRIBUTION

Fig. 4.4 shows the curves between headloss and depth plotted for various times. At zero hours, the headloss is due to the clean bed only. The theoretical and experimental values of total headloss are very close. Experimental value is 12.6 cm against the calculated value of 14.6 (sec. 4.4).

At all hours it is evident that there are two curves which join together at 16 cm depth. It is due to the presence of two materials. Headloss increase in the first curve is slower than the second. For the upper 15 cm depth of the bed the material is cinder with coarser grains and more porosity. It will have less surface area also with a result that removal due to mechanical straining as well as adsorption will be less.

At 46 hour, the headloss for first 15 cm depth is 48 cm and for next 15 cm it is 70 cm. The top 15 cm is cinder which allows the turbidity to pass through and let the lower layers be utilized in removing turbidity. This difference in headloss is more evident at later hours only. At 34 hours the headloss for first 15 cm depth is 20 cm and for next 15 cm it is 24 cm. This indicates that headloss in the top sand layer becomes more at later hours. This would mean that ultimate value of the specific deposit in the layer just below cinder is reached before that in cinder. Fine sand at top is mixed with cinder and forms a mixed layer in which the headloss pattern is more like that in the sand below it. Conley (15) working with filters at Hanford has suggested that intermixing of two layers has a favourable influence on hadloss because fine sand can not form impervious mat when mixed with coarse grains above it.

Headloss increase with time is almost linear except at the end of filter run when headloss increase rate is more. The linear increase in headloss is expected as headloss is linearly related to specific deposit which in turn changes with time linearly.

5.2.2 FILTER PERFORMANCE

There is 100% removal upto a period of 43 hours and an increase in the turbidity of effluent is seen when

filter run is increased beyond 43 hours. Depth of penetration slowly increases with time and ultimately effluent starts getting turbid. At 2 hours all the turbidity is arrested in top 16 cm and at 24 hours depth of penetration is 24 cm.

A 16 mg/l of turbidity is found in the effluent for a filter run beyond 43 hours. This increase in effluent turbidity is associated with a decrease in turbidity at 16 cm for 46 hours length of run (Fig. 4.7). Therefore it is clear that some of the turbidity which was to be arrested in upper layers moves down. This is because of the reason that coarse grain cinder is not able to remove turbidity beyond a period of 43 hour or the floc starts disintegrating. This was also seen by Conley at Hanford (15). He suggested the use of filter conditioners if they do not cause much of headloss. There is another reason which might have been responsible for this turbidity increase, that is, at the end of the filter run rate of control becomes difficult because of the rapid drop in the rate of flow. Any sudden opening of value no. V5 would have produced an agitation in the bed and thus resulting effluent turbidity.

Turbidity first increases with depth because of the reason that some time is taken before the floc is formed. As soon as floc is formed there is a increased obstruction to the flow with a consequent increase in turbidity at certain depth.

5.3 ADVANTAGES OF USING TOP LAYER OF CINDER

It is seen that for a headloss of 150, the length
of run in case of conventional filter was 31 hours however the
same for the filter with top layer as cinder is 43 hours.
For a headloss of 150 cm the percentage of removal for both
the filters is 100 percent. This will mean more water can be
produced without needing a backwash when cinder is used as a
top layer. Water produced per filter run for the conventional
filter is 3720 gallons per square foot of the filter area
and for this it would be 5160 gallons per square foot of the
filter area. This means a improvement in the efficiency of
the filter to produce treated water.

As the length of run is increased there will be
saving in the amount of backwash water needed. Although total
amount of floc deposited at the end of the length of run will
be more in case of sand-cinder filter but amount of water
needed for backwash will be unchanged. Therefore amount of
backwash water needed per unit volume of the treated water
will be lower in case of sand-cinder bed.

As we go beyond the headloss of 150 cm, the
efficiency of removal is decreased and if efficiency of
removal is improved the length of run in sand-cinder could be
increased up till a head of 200 cm is reached. There could be
two alternatives to do this, either extra chemical use is

made or sand depth is increased. In past, an increase in sand depth have been found economical for higher filtration rates (15).

5.4 PERFORMANCE OF CONVENTIONAL AND CINDER-SAND FILTER AT HIGHER FILTRATION RATE

At 3 gpm the length of run for 150 cm headloss is 30 hours for sand-cinder filter and 25 hours for conventional filter. Even for high flows the length of run in sand-cinder filter is more and total amount of water produced is 5400 gallons/sq. ft. for sand-cinder filter and 3500 gallons/sq.ft. for sand filter. Therefore total water treated per run or per unit final headloss is more in case of sand-cinder bed and it is also more than that produced at 2 gpm.

When efficiency of removal is considered, in case of sand-cinder filter only 67% removal takes place. This can be improved either using more chemicals or increasing the sand depth.

The length of run for a headloss of 150 cm and for a flow of 4 gpm is 20 hours in case of sand-cinder filter and 15 hours in the sand filter. Its total volume of water treated per run is considered, at 4 gpm amount of water is 4800 gallons/sq.ft. per run in sand-cinder filter and 3600 gallons/sq.ft. per run for sand filter. It is seen that total amount of water treated per run for a head loss of

150 cm is almost same for all flows in case of sand filter as well as for sand-cinder filter. At 4 gpm efficiency of removal is also poor and only 50% removal takes place for 150 cm headloss.

It has been found difficult to control the rate of flow at the end of the filter run in case of higher flows. The intermitant manual control might be the reason for excessive effluent turbidity. A continuous flow control is necessary for the experiments at higher filtration rates.

CONCLUSIONS

1. Using 15 cm cinder bed over the sand, the efficiency of the filter is improved. For a flow of 2 gpm/sq.ft., 100% removal is obtained for a filter run of 43 hours with influent turbidity of 100 mg/l and alum dose of 10 mg/l introduced at 6 cm below ~~above~~ the bed.

2. At 2 gpm flow, the volume of water treated (100% removal) per unit of total headloss increased from 24.8 gal/sq.ft. per cm to 34.4 gal/sq.ft. per cm.

3. For flow higher than 2 gpm, the amount of water produced per unit of final headloss is not very much changed and the efficiency of removal at the end of run has been found to be poor.

4. Although long term properties of cinder as a filter media has not been tested, but it satisfies the essential requisite properties for its suitability as a filter media.

5. It has been found difficult to control the rate of flow at the later stages of runs for flows higher than 2 gpm.

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APPENDIX

TABLE NO. A.1   Turbidity vs Absorbance

Wave length = 390 milli micron

Turbidity (mg/l)	10	20	40	60	80	100	150	200
Absorbance	0.010	0.015	0.025	0.035	0.050	0.060	0.090	0.120

TABLE NO. A.2   Sieve analysis of sand

Size in mm	0.599	0.422	0.295	<.295
B.S.S. no.	25	36	52	Remaining
Wt. retained in grams	0.0	292.4	17.3	6.3
Cumulative wt. finer than in grams	316	23.6	6.3	-
% Finer than	100	7.5	2.0	-

TABLE NO. A.3   Sieve analysis of cinder

Size in mm	0.853	0.599	0.422	<0.422
B.S.S. no.	18	25	36	Remaining
Wt. retained in grams	0.0	183.7	8.3	1.0
Cumulative wt. finer than in grams	193	9.3	1.0	-
% Finer than	100	4.8	0.5	

TABLE NO. A.4   Specific gravity of cinder

Wt. of dry cinder   = 39.1 grams

Wt. of the bottle + water   = 628.5 grams

Wt. of bottle + cinder + water   = 634.1 grams

Specific gravity of cinder   =   1.17

TABLE NO. A.5   Solubility of cinder in HCl.

Initial wt. of well washed dry cinder = 50.7 grams

Final wt. of dry cinder   = 48.2 grams

Percentage loss by wt.   =   0.49%

TABLE No. A.6   Relative expansion of sand and cinder

Filter bed = 17 cm sand + 8 cm cinder

Depth of mixed layer = 1.0 cm

Sand

Flow rate (ml/min)	Flow rate (cm/min)	Initial depth	Final depth	% Expansion
1	2	3	4	5
1720	39	17	8.4	8.5
2700	61	17	20.9	23.0
3100	78	17	22.9	34.0
4060	92	17	23.7	39.0

Sand + cinder

1	2	3	4	5
1770	40	25	27.6	11.0
2610	59	25	30.9	24.5
3620	82	25	34.6	38.5
3930	89	25	35.9	44.0

Cinder

1	2	3	4	5
1770	40	8	9.4	18.0
2610	52	8	10.5	32.0
3620	82	8	11.6	45.0
3930	89	8	12.3	54.0

TABLE No. A.7   Filter run no. 1 (COLUMN-1)

Flow = 2 g.p.m./sq.ft.

Influent Turbidity = 100 mg/l

Alum dose = 10 mg/1

Depth (cm)	Headloss (cm)						Turbidity (mg/l)					
	9	$16\frac{1}{2}$	24	47	$85\frac{1}{2}$	93	9	$16\frac{1}{2}$	24	47	$85\frac{1}{2}$	93
Hour												
0	3.3	5.1	6.6	9.4	11.2	11.4	0	0	0	0	0	0
1	3.5	6.1	6.9	10.1	14.6	14.6	33	16	0	0	0	0
2	3.6	6.3	7.4	10.3	15.7	15.9	33	16	25	0	0	0
3	3.8	6.5	7.9	10.9	18.3	18.8	75	50	0	00	0	0
4	3.9	6.9	8.5	11.1	20.8	21.1	100	33	16	0	0	0
5	4.3	7.1	9.2	13.1	23.6	33.8	133	116	33	0	0	0
6	4.5	7.8	10.5	15.2	25.7	26.1	166	200	133	8	0	0
8	4.8	8.2	11.1	20.8	27.5	28.0	200	116	67	0	0	0
17	6.1	9.3	14.9	33.7	42.4	42.9	383	150	67	0	0	0
20	7.1	10.0	17.9	40.0	53.6	54.8	467	300	100	0	0	0
24	7.7	13.5	20.1	44.3	62.5	63.7	483	433	216	33	0	0
28	8.5	16.8	26.0	54.0	73.5	74.9	550	467	183	166	0	0
32	10.1	19.8	29.9	63.8	82.5	86.0	533	533	200	67	0	0
34	12.1	22.3	33.1	73.9	93.0	94.0	583	550	300	67	0	0
40	16	28.7	41.1	96.6	120.1	123.0	600	567	550	67	0	0
42	16.5	29.6	45.1	97.8	128.5	129.9	593	366	383	83	0	0
45	31.3	50.3	93.7	156.8	177.9	179.5	567	600	383	100	8.3	8.3
46	31.8	51.0	94.5	157.7	178.8	180.5	533	583	433	116	16.6	16.6

TABLE No. A.8   Filter run no. 1 (COLUMN 2)

Flow – 2 g.p.m.

Depth	Headloss (cm)						Turbidity (mg/l)					
	9	$16\frac{1}{2}$	24	47	$85\frac{1}{2}$	93	9	$16\frac{1}{2}$	24	47	$85\frac{1}{2}$	93
Hour												
0	4.1	6.6	8.0	11.1	12.3	12.6	0	0	0	0	0	0
1	5.3	8.8	12.0	15.1	16.2	16.6	25	0	0	0	0	0
2	6.0	9.8	13.1	16.2	17.4	17.8	50	0	0	0	0	0
3	6.5	12.5	15.7	18.9	20.1	20.3	60	16	0	0	0	0
4	6.9	14.1	15.0	23.0	27.6	27.9	133	33	0	0	0	0
5	7.2	15.5	16.1	27.1	31.7	32.0	183	33	16	0	0	0
6	8.6	17.0	19.0	30.9	35.6	35.9	350	67	0	0	0	0
8	11.0	19.5	22.8	34.5	39.7	40.1	333	83	0	0	0	0
17	22.7	39.8	53.7	74.5	82.8	83.9	433	133	16	0	0	0
20	31.0	48.9	62.8	84.5	92.9	93.9	383	167	67	0	0	0
24	33.1	50.7	68.2	93.4	104.1	105.0	550	333	167	16.7	0	0
28	39.9	66.7	87	116.1	129.8	130.5	500	350	150	33	0	0
32	45	74.3	93.7	137.9	157.3	158.9	616	367	167	50	0	0
34	51.5	86.1	109.8	150.3	173.4	115.1	633	383	216	50	0	0

TABLE No. A.9   Filter run no. 2 (COLUMN-1)

Flow - 3 g.p.m.

Depth	Headloss (cm)							Turbidity (mg/l)					
	9	$16\frac{1}{2}$	24	47	$85\frac{1}{2}$	93		9	$16\frac{1}{2}$	24	47	$85\frac{1}{2}$	93
Hour													
0	3.6	5.8	7.1	12.6	15.9	16.1		0	0	0	0	0	0
1	3.8	6.2	7.9	14.2	17.7	18.9		33	16	0	0	0	0
2	4.1	6.9	8.9	16.7	20.6	24.4		67	33	0	0	0	0
3	4.4	7.3	10.4	18.2	23.9	26.2		67	67	0	0	0	0
4	5.1	8.1	12.7	21.3	30.1	31.1		100	67	0	0	0	0
6	6.3	9.0	14.0	24.3	36.2	36.8		167	150	133	0	0	0
8	6.9	12.4	18.5	31.2	44.0	45.1		267	267	200	0	0	0
16	11.1	17.7	27.5	57.2	72.3	72.9		333	300	267	16	0	0
20	13.7	24.3	38.9	72.5	85.1	87		467	416	350	150	0	0
24	20.9	30.5	47.1	90.5	102	102.5		500	516	416	167	0	0
28	26.9	46.1	59.8	110.1	137.8	138.4		533	550	450	233	33	33
$32\frac{1}{2}$	33.4	51.2	96.0	146.5	175.9	176.8		616	600	516	267	67	67

TABLE No. A.10   Filter run no. 2 (COLUMN-2)

Flow - 3 g.p.m.

Depth	Headloss (cm)						Turbidity (mg/l)					
	9	$16\frac{1}{2}$	24	47	$85\frac{1}{2}$	93	9	$16\frac{1}{2}$	24	47	$85\frac{1}{2}$	93
Hour												
0	7.1	9.9	14.0	16.2	18.1	18.3	0	0	0	0	0	0
1	8.2	10.8	18.0	18.7	19.3	20.2	50	16	0	0	0	0
2	9.8	11.0	19.0	20.1	25.9	26.1	67	50	0	0	0	0
3	10.2	13.1	18.3	21.0	27.3	28.1	67	50	0	0	0	0
4	10.4	15.7	16.2	27.3	33.1	33.7	100	67	0	0	0	0
6	10.7	19.4	26.3	36.1	38.2	38.7	200	167	116	0	0	0
8	13.7	26.5	33.2	45.2	48.1	48.4	316	300	216	0	0	0
16	23.9	34.2	47.5	68	86.9	87.4	500	433	316	33	0	0
20	22.6	28.1	59.2	90.1	113.7	114.2	616	516	367	100	0	0
24	34.6	53.4	70.5	103.9	133.7	135.9	633	550	416	167	0	0
28	49.9	74.2	98.1	150.5	176.4	177.2	662	633	516	250	0	0
$32\frac{1}{2}$												

TABLE No. A.11   Filter run no. 3 (COLUMN-1)

Flow - 4 g.p.m.

Depth	Headloss (cm)						Turbidity (mg/1)					
	9	$16\frac{1}{2}$	24	47	$85\frac{1}{2}$	93	9	$16\frac{1}{2}$	24	47	$85\frac{1}{2}$	93
Hr.												
0	7.5	11.3	17.4	28	36.9	37.1	0	0	0	0	0	0
1	8.4	13.2	19.4	32.1	39.7	43.1	67	33	0	0	0	0
2	9.6	15.7	21.7	36.7	44.7	50.2	67	33	16	0	0	0
3	10.2	16.9	23.2	41.2	54.1	54.5	83	67	33	0	0	0
4	11.3	17.8	25.9	47.1	60.0	60.4	116	100	83	0	0	0
6	12.9	20.1	28.4	53.4	69.6	65.7	216	183	150	16	0	0
8	14.5	23.7	32.8	61.5	81.9	82.1	283	250	183	67	16	16
16	18.2	29.0	44.1	91.0	129.3	132.7	450	400	316	133	50	50
18	20.9	34.5	49.0	101.4	137.9	140.7	516	500	433	216	67	67
20	25.1	39.8	51.5	112.3	149.0	151.2	633	633	553	300	83	83
24	31.8	47.1	76.0	147.9	177.0	177.5	683	633	583	350	83	83

TABLE No. A.12   Filter run no. 3 (COLUMN-2)

Flow - 4 g.p.m.

Depth	Headloss (cm)						Turbidity (mg/1)					
	9	$16\frac{1}{2}$	24	47	$85\frac{1}{2}$	93	9	$16\frac{1}{2}$	24	47	$85\frac{1}{2}$	93
Hr.												
0	6.9	14.2	17.0	26.2	31.0	31.5	0	0	0	0	0	0
1	7.7	15.7	19.1	28.8	33.5	41.5	83	50	0	0	0	0
2	9.8	17.1	21.7	33.9	39.1	50.4	83	67	16	0	0	0
3	11.2	18.5	24.2	41.7	51.0	51.6	116	100	50	0	0	0
4	13.8	20.2	28.9	48.0	65.1	66.9	167	150	116	0	0	0
6	15.2	23.7	33.8	59.7	77.2	85	267	233	183	16	0	0
8	18.4	29.8	42.5	71.0	94.2	96.4	383	367	267	67	16	16
16	37.9	60.9	84.4	127.4	155.1	156	667	616	500	183	50	50
18	53.2	84.6	109.8	157.1	178.0	178.4	833	716	650	316	83	83
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